

**Compilation of 1991 Annual Reports
of the Navy ELF Communications System
Ecological Monitoring Program**

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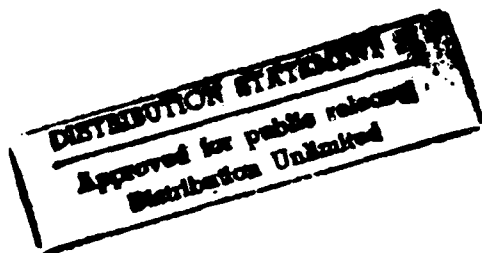


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Volume 3 of 3 Volumes:
Tabs G-I

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FOREWORD

During 1991, the Navy continued to conduct long-term studies monitoring for possible effects to biota from operation of their ELF Communications System. The Space and Naval Warfare Systems Command (SPAWAR) funded these studies through a contract to IIT Research Institute (IITRI). IITRI provided engineering support and overall program management of monitoring studies performed by university subcontractors.

The reports compiled (Tabs A-H) in this three-volume document present the progress and findings of ongoing studies located near the Naval Radio Transmitting Facility--Republic, Michigan. At least three scientific peers reviewed each report. Study investigators considered the peer critiques prior to providing a final copy of their annual report to IITRI. These annual reports are compiled here without further change or editing by SPAWAR or IITRI. As is done for all program documents, IITRI has submitted this compilation to the National Technical Information Service for unlimited distribution. Past compilations and other program documents are listed under Tab I.

**ELF COMMUNICATIONS SYSTEM
ECOLOGICAL MONITORING PROGRAM**

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- G. Bird Species and Communities:
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**ELF COMMUNICATIONS SYSTEM ECOLOGICAL MONITORING PROGRAM:
BIRD SPECIES AND COMMUNITIES**

ANNUAL REPORT: 1991

SUBCONTRACT NUMBER: E06595-88-C-011

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ELF COMMUNICATIONS SYSTEM ECOLOGICAL MONITORING PROGRAM:

BIRD SPECIES AND COMMUNITIES

ANNUAL REPORT: 1991

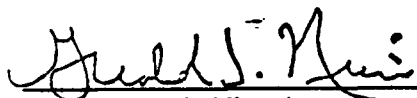
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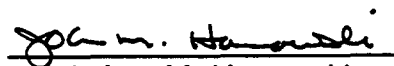
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SUMMARY

This investigation was designed to isolate effects of electromagnetic (EM) fields produced by extremely low frequency (ELF) antenna systems on bird species breeding in or migrating through Wisconsin and Michigan. Specifically, we seek to determine if bird species richness and abundance differ between areas that are close to the antenna and those that are far enough away to be unaffected by the antenna. We are pursuing this question at both the community and species level. Characteristics examined include total species richness and abundance, abundances of common bird species, and abundances of birds within selected guilds. Our monitoring program has included bird censuses in both states over a five month period from May to September, 1986-1991. Additional data were collected in August-September 1984 and in June 1985, in both states. Bird censuses were terminated in Wisconsin after 1989 but are continuing in Michigan.

No consistent patterns have yet emerged to demonstrate that birds are more or less abundant on treatment relative to control segments in either state after effects of habitat are accounted for. Further, few significant differences have been found at the community or species level; differences in one season or year are not always repeated in subsequent years or seasons. Most differences that exist between treatment and control transects can be attributed to habitat differences or chance rather than to electromagnetic field differences.

ABSTRACT

This investigation was designed to isolate effects of electromagnetic (EM) fields produced by extremely low frequency (ELF) antenna systems on bird species breeding in or migrating through Wisconsin and Michigan. Specifically, we seek to determine if bird species richness and abundance differ between areas that are close to the antenna and areas far enough away to be unaffected by the antenna. We are pursuing this question at both the community and species level. Characteristics examined include total species richness and abundance, abundances of common bird species, and abundances of birds within selected foraging and habitat guilds. Our monitoring program has included bird censuses over a five month period from May to September (1986-1991). Additional data were collected in both states during August and September of 1984 and during June of 1985. Research in Wisconsin was completed in 1989 (Hanowski et al. 1991), but has continued in Michigan.

Here we summarize results of our 1991 research activities in Michigan. The Michigan transmitter began 150 amp tuning and testing intermittently in the first part of May 1989. On 14 May, the transmitter began continuous 150 amp operation for 16 hrs/day on weekdays and all day on weekends. On 7 October 1989, the Michigan transmitter began continuous operation at full power.

Overall, bird abundance and species diversity were highest and approximately the same during June and July throughout all study areas. Bird abundance and species diversity were significantly higher on control segments during May and July, but no other differences in community level parameters were significant. Considerable annual variation in numbers of individuals and species was noted. Particularly common species (all seasons combined) included Black-capped Chickadee, Golden-

crowned Kinglet, Hermit Thrush, Red-eyed Vireo, Nashville Warbler, Black-throated Green Warbler, Ovenbird, and White-throated Sparrow. The most abundant species present on treatment and control segments varied among seasons.

Twenty-seven of 193 comparisons (14%) of individual species between treatment and control segments were significantly different. Abundances were higher on treatment segments in 20 cases (74%). Few species, however, were consistently and significantly more abundant on either treatment or control segments among seasons within a year or within seasons among years. Differences between treatment and control segments were most likely due to habitat differences.

Species were classified into guilds on the basis of foraging behavior and preferred breeding habitat. Few significant differences in abundance of birds within different guilds were found between treatment and control segments. Differences were most consistent for habitat categories (e.g., birds that prefer deciduous forest were more abundant on control segments in 4 of 5 months), providing further evidence that habitat differences were responsible for many of the observed differences in bird distribution patterns between treatment and control segments.

Previous analyses of vegetation on Michigan study sites (Blake et al. 1988) revealed differences between treatment and control plots. The difference most likely to influence bird populations was distribution of coniferous and deciduous habitats. Treatment segments supported more coniferous and lowland habitats than did control segments. It is important to note that habitat differences that exist between treatment and control areas will not affect our analysis of antenna effects. The Michigan study is designed as a before-and-after experiment; we can compare changes in bird abundance over time on treatment segments and on control segments. If

electromagnetic fields produced by antenna operation affect bird distribution patterns, we expect to detect a change in patterns of abundance between treatment and control areas. Such changes, if they occur, would be independent of already present habitat differences.

To investigate this possibility, we analyzed changes in species abundances over time on treatment and control segments, comparing differences in amount of change from pre-treatment (1986-1987), to partial treatment (1988), and full treatment (1989 onwards) years (see Niemi and Hanowski 1991; Appendix 2). Few differences were significant; in 1991, no community level parameters showed a significant difference and in only 7 cases (5.3% of those tested) were differences significant at the species level. These results indicate that the amount of change in bird abundance from pre-treatment to post-treatment conditions did not differ on treatment and control segments. Thus, there is no evidence to indicate that electromagnetic radiation produced by the ELF antenna has affected bird populations on our study sites.

INTRODUCTION

Natural disturbances are increasingly recognized as integral components of most, if not all, biotic communities (Pickett and White 1985). Disturbances vary on both temporal and spatial scales and can substantially affect structure and organization of communities as well as the population dynamics of individual species. Anthropogenic disturbances also influence most, if not all, communities; these latter disturbances frequently are cause for concern because of their potential to disrupt population dynamics and community structure.

The types of disturbances caused by human activities are numerous and, like natural disturbances, differ in level of intensity and effects on populations and communities. One of the most ubiquitous disturbances is the network of transmission lines that crisscross the country. These transmission lines form long, linear breaks in the natural cover and emit electromagnetic (EM) radiation of different intensities. Potential effects of EM radiation, from various sources, have been the subject of much recent attention (Carstensen 1987, Pool 1990a-c).

Effects of extremely low frequency (ELF) electromagnetic fields on birds are poorly understood (National Academy of Sciences 1977; Lee et al. 1979; other references in Hanowski et al. 1987, 1991). Several investigators have studied effects of transmission lines on structure and composition of bird communities; most have analyzed combined effects of habitat alteration and EM fields (Anderson et al. 1977; Anderson 1979; Dawson and Gates 1979; Meyers and Provost 1979; Stapleton and Kiviat 1979; Bell 1980; Bramble et al. 1984; Niemi and Hanowski 1984). Others have focused on effects of the right-of-way (ROW) edge (Chasko and Gates 1982;

Kroodsma 1982), collision with lines (Beaulaurier et al. 1982), and audible noise generated by a transmission line (Lee and Griffith 1978). To our knowledge, our recently completed study on effects on birds of EM fields produced by the US Navy's ELF transmission facility in Wisconsin (Hanowski et al. 1991), was the first that attempted to separate effects of EM fields on bird species and communities from effects due to habitat changes along the ROW. That study produced no convincing evidence that birds were either attracted to or repelled by EM fields produced by the antenna.

The current investigation in Michigan, and the recently completed Wisconsin study, were designed to isolate effects of EM fields produced by ELF antenna systems on bird species breeding in or migrating through Wisconsin and Michigan. Our goal was to determine if distribution and abundance of bird species differed between areas that were close to the antenna and those that were far enough away to be unaffected by EM fields produced by the antenna. Our study has encompassed spring migration (May), early (June) and late (July) breeding, and early (August) and late (September) fall migration. Potential effects of the ELF antenna on birds may vary among seasons. During migration, birds may be present on study areas for only brief periods. Conversely, breeding birds remain on territories longer (1-3 months), increasing their exposure to EM fields.

To assess effects of the ELF antenna on bird communities we can either: (1) compare the affected area (treatment) with a similar control area; or (2) conduct a before-and-after study on both control and treatment plots. The former approach was used in Wisconsin because the antenna already was in operation at the start of our

study. Research in Michigan was, in contrast, initiated before the antenna began operation. By following changes in bird numbers over time on areas affected by the antenna and on unaffected areas, we can separate any effects of the antenna on birds from effects of more regional variables (e.g., annual variation in rainfall) and from effects arising from differences in vegetation structure between control and treatment areas. The Michigan transmitter was tested intermittently, at less than full power during parts of our 1988 field season and at full power during most of our 1989 field season. Continuous operation at full power began on 7 October 1989. Therefore, 1991 represents the third full impact year. In the following we summarize our research activities in Michigan for 1991, the sixth year in which censuses were conducted during all seasons.

EXPERIMENTAL DESIGN

The first steps in the experimental design were to (1) evaluate techniques for sampling birds; and (2) determine sample sizes required to detect a specified difference between control and treatment areas. We examined four potential sampling techniques: transect counts, point counts, territorial mapping, and mist-netting. Territorial mapping and mist-netting were eliminated from consideration because of the amount of effort required to obtain statistically reliable results. We selected transect counts instead of point counts because the ELF communications system consists of a long, linear network of antenna and ROW and transects could be run parallel to this network. Transects also included a larger sample area than would have been included in point counts.

In an ideal experimental design, each sample unit should be randomly assigned to control and treatment areas. Logistically, however, this arrangement would be inefficient. To balance statistical rigor with the practicalities of working in the field, we decided to group eight 500 m segments (each segment = one experimental or sample unit) into one long transect line (hereafter called transect; Fig. 1). Each 500 m segment was separated by a buffer of 50 m to reduce autocorrelation between the experimental units. We used Moran's I statistic (Sokal and Oden 1978) to test spatial autocorrelation of adjacent segments. Results indicated that a 50 m buffer eliminated most autocorrelation between adjacent segments (Hanowski et al. 1990).

We grouped eight segments in a single line because our previous experience indicated that bird counts should be conducted from one half hour before to about four hours after sunrise. A total of 4 hours and 35 minutes are needed to count birds along eight segments and seven buffers (30 minutes for each segment and 3 minutes for each buffer). We estimated that 39 segments were needed in each group (control and treatment) to detect a 15% difference in number of species (Hanowski et al. 1990). This percent difference was selected based on an ability to detect a difference of one species between control and treatment areas. Therefore, we selected five transect starting points per group, for a total of 80 segments (40 treatment and 40 control segments).

Placement of treatment transects with respect to the ELF antenna system was designed to achieve two goals: (1) to reduce or eliminate potential effects of the ROW edge on the bird community (Chasko and Gafis 1982); and (2) to maintain an appropriate EM field within the treatment area. We placed the transects parallel to

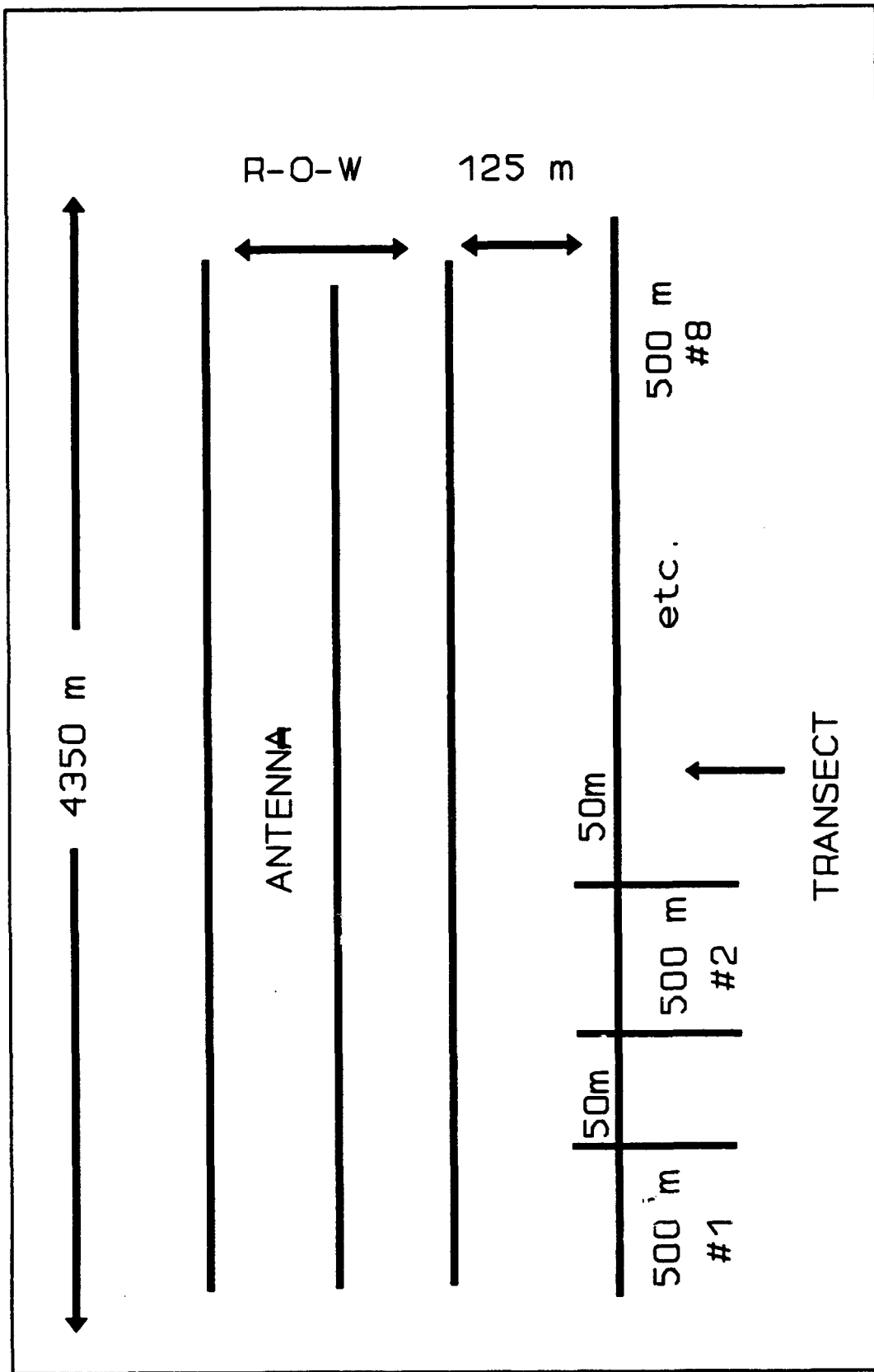


Figure 1. Schematic of a treatment transect layout. ROW = right-of-way.

and 25 m from the edge of the ELF antenna ROW (Fig. 1). This achieved a 25 m buffer from the limits of where we recorded birds (100 m) to the ROW edge. Although this placement reduced the intensity of EM fields within treatment areas, EM fields were still high enough to achieve the 10:1 ratio between treatment and control areas required in the study specifications (Brosh et al. 1986).

STUDY AREAS

Starting locations for five control and five treatment transects were randomly selected (Fig. 2; see Niemi and Hanowski 1986, Hanowski et al. 1991 for details). Electromagnetic fields were measured to insure that 76 Hz EM fields at a treatment site were significantly larger than: (1) 76 Hz EM fields at control sites, (2) 60 Hz fields at treatment sites, and (3) 60 Hz fields at control sites. In addition, exposure criteria required that there be no substantial difference in the ambient 60 Hz EM fields between control and treatment transects (Brosh et al. 1986). Electromagnetic fields were measured at the beginning and ending points for each transect; they were not completed for each transect segment because most were not easily reached (e.g., most are 1-4 km from a road). Eight of 25 transect pairs in Michigan were determined to be "conditionally acceptable" with respect to EM field ratios established by IITRI, based on data collected in 1986. Previous data placed all pairs in the "acceptable" category (Haradem et al. 1987). All transects still satisfy the EM exposure criteria and will be used for the remainder of the monitoring period.

Information regarding proposed logging along the transects was obtained from Department of Natural Resources in Michigan. Five control and five treatment transect segments were scheduled for logging in Michigan effective through 1990

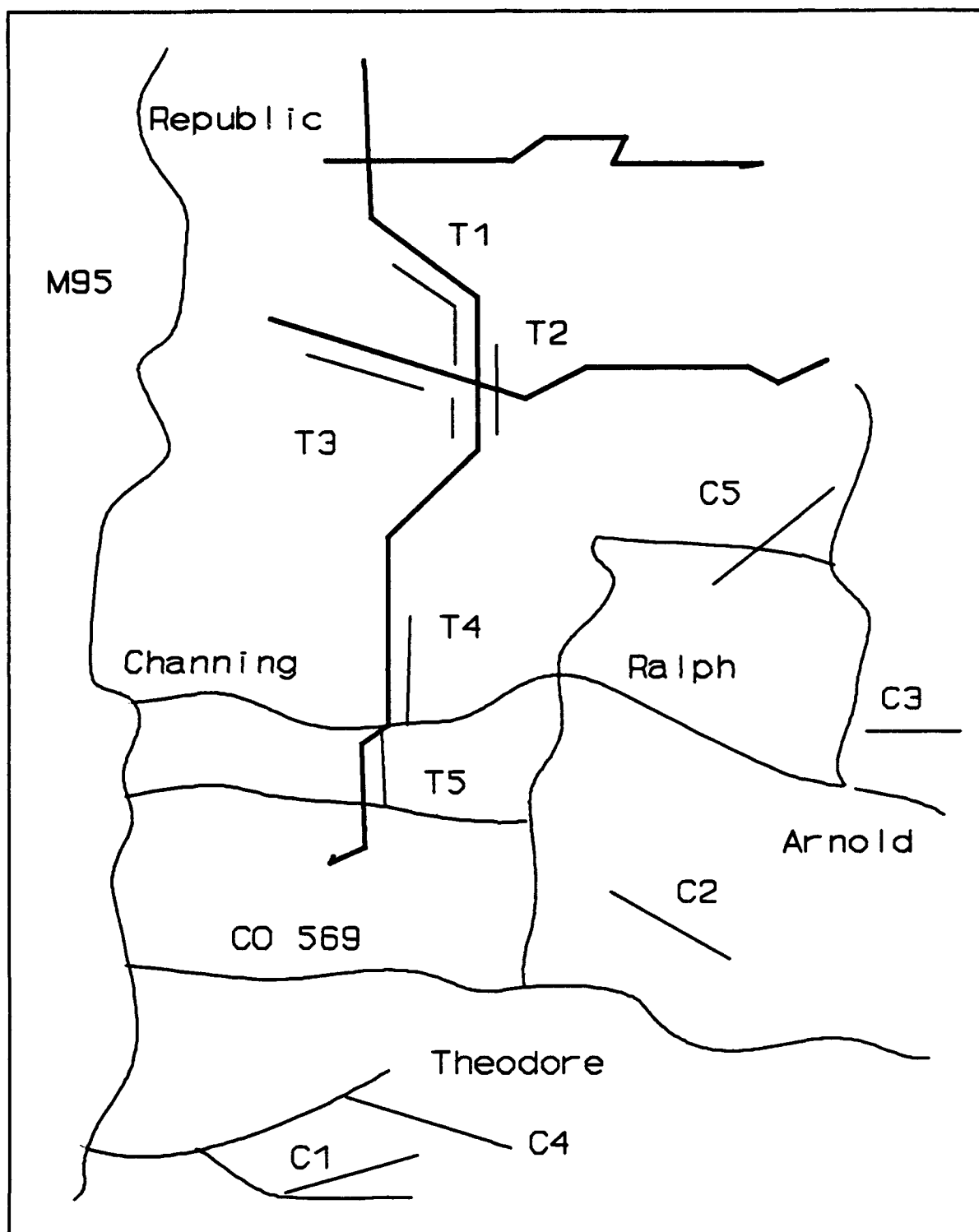


Figure 2. Locations of control (C1 to C5) and treatment (T1 to T5) transects in Michigan.

(Table 1). Several 500-m transect segments in Michigan have been partially logged since this study started (Table 1). The Michigan Department of Natural Resources agreed to delay most additional logging until 1992. Analyses of annual variation in bird community composition revealed that segments logged over <20% of total length showed no greater difference in bird populations between years than did unlogged sites. Segments that were logged over all or most of their length showed significantly greater differences in bird species composition between years than did unlogged segments. Consequently, our analyses of bird distribution patterns between years omit segments logged over more than 20% of their length.

METHODS

We counted birds along each 500 m segment (40 control and 40 treatment) during early May (spring migration and arrival of breeding residents), June (early breeding), July (late breeding), August (early fall migration), and September (late fall migration). Counts were started approximately one half hour before sunrise and lasted up to approximately 4.5 hours after sunrise on days with little wind (<15 km/hr) and little or no precipitation. Eight transect segments were censused by each observer daily. Each observer walked at a rate of 30 min/500 m segment and recorded the identity and location of all birds observed (by sight or sound) within 100 m of the segment center line.

We randomly assigned counts of control and treatment transects (eight 500 m segments/transect) to each of two observers, with the restriction that each observer

Table 1. Summary of Michigan transect locations and proposed logging of study areas effective through 1991. Asterisks denote sections that were logged in 1987 (*), 1988 (**), 1989 (***), and 1990 (****). No additional study areas in Michigan are scheduled to be logged before the end of the study.

Number and Name affected	Township	Range	Sections	Number of 500 m segments
C1 Carney Lake	41N	29W	33,34,35,36	2 (1992)
C2 Skunk Creek	42N	28W	14,23,24	2 (1992)
	42N	27W	19,30	
C3 Arnold	43N	25W	31,32,33,34	1 *
	43N	25W	32	1 ***
C4 Lost Lake	41N	29W	21,26,27,28,35	2 **
C5 Bob's Creek	44N	26W	13,23,24,26	1 ****
T1 Heart Lake	45N	28W	7,18	1
	45N	28W	19	1 ***
T2 Flat Rock Creek	44N	28W	6	3 *
	45N	28W	19,30,31	
T3 Schwartz Creek	45N	28W	31	2 **
	45N	29W	26,27,35,36	
T4 Turner Road	43N	29W	1,11,12	0
	44N	29W	36	
T5 Leeman's Road	43N	29W	14,23,26,35	0

sample the same number of control and treatment segments. Control and treatment transects were sampled simultaneously by the two observers.

We used the number of individuals observed in all data analyses instead of attempting to calculate a density value. Density could be calculated with a variety of formulae (Emlen 1971, 1977; Järvinen and Väisänen 1975; Burnham et al. 1981), but there are several assumptions that must be met before these methods can be used. A critical assumption is that distances are measured accurately; such measurements are difficult to obtain when birds are heard but not seen, as is true for most birds recorded during counts. Without accurate distance estimates, these methods do not provide valid density estimates. Instead, density estimates provide an index that may be no better than the original counts (Wilson and Bart 1985). In addition, estimates of density are not needed in most investigations, especially when comparisons of "relative density" are less costly and allow the investigator to meet the objectives of the experiment (see Verner 1985). Here, we only assumed that the number of birds recorded was related to the density of birds in an area (Raphael 1987) and that bird detectability was similar within control and treatment areas.

We classified each species by (1) nesting area, (2) food or foraging type, (3) breeding habitat preference, and (4) migration strategy (Appendix 1), using published sources (e.g., Martin et al. 1951; Bent 1963, 1964; Green and Niemi 1978; Terres 1982; AOU 1983; Blake and Karr 1984) and personal observations. Previous analyses (Blake et al. 1988) indicated that differences between treatment and control segments were most likely to occur among groups defined on the basis of foraging

behavior and breeding habitat. Consequently, we used those guilds in analyses of the effects of the ELF antenna during 1991.

STATISTICAL ANALYSES

WITHIN YEAR COMPARISONS

We used one-way analysis-of-variance (ANOVA) or Kruskal-Wallis test (Sokal and Rohlf 1981) to test for differences between control and treatment segments for the following variables: (1) mean number of individuals observed in a 500 m segment in control or treatment areas during each season; (2) mean number of species observed in a 500 m segment in control or treatment areas during each season; and (3) mean abundance of individual species on control or treatment areas.

Variables were examined for normality of residuals (Wilk-Shapiro test; skewness and kurtosis) and homogeneity of variance (Bartlett's test) prior to statistical analyses (Sokal and Rohlf 1981). Variables were transformed where necessary (e.g., logarithmic, square root) to reduce skewness, kurtosis, and heterogeneity of variances. A nonparametric test (Kruskal-Wallis test) was used when assumptions were not met, even after transformation.

In previous years (e.g., Blake et al. 1991), we used G-tests to compare distribution and abundance of less common species on treatment and control segments on the basis of prominence values:

$$PV = D * F^{.5},$$

where D = number of individuals observed and F = the relative frequency of species occurrence on treatment or control segments. The prominence value weights both the frequency of occurrence and number of individuals (Beals 1960; Blake 1982) and

therefore provides a useful description of bird distribution patterns. However, because the count data are transformed, it is not strictly correct to compare differences based on G-tests. Consequently, we decided to use Kruskal-Wallis tests in this (and all future reports) to compare differences in abundance on treatment and control segments of these less abundant species; the large sample size (40 segments per treatment or control) permitted us to do this. To facilitate comparisons with previous years, we reanalyzed results previously based on prominence values.

AMONG YEAR COMPARISONS

We used two approaches to analyze distribution patterns among years. (Because some segments were affected by logging after the initial census in 1985, we excluded logged segments [$>20\%$ logged] in analyses of annual variation.) First, we examined annual differences by season for number of species and individuals using a two-way ANOVA. Second, we compared changes among years in abundances of birds on treatment segments to changes that occurred on control segments. If antenna operation affected bird distribution patterns, we would expect a greater mean change per segment on treatment than on control segments. We combined data from 1986 and 1987 from each segment to provide a pre-treatment basis for comparison. We then compared the average change or difference in abundance on treatment and control segments; comparisons were made between pre-treatment values and those of all subsequent years. The antenna was in partial operation during 1988, considered a partial treatment or "intermittent" year. Full treatment years are from 1989 on. We used t-tests for all comparisons of mean differences. A full description of our pre- and

post-operational analyses, results of analyses through 1990, and a summary of antenna operation are in Appendix 2.

PROBABILITY VALUES

To simplify and condense the results section, we eliminated all probability (P) values from the text. Any difference stated in this section was significant to at least the $P < 0.05$ level.

RESULTS

WITHIN-YEAR COMPARISONS

Species Richness and Abundance of Individuals

Total number of species and individuals observed varied among seasons on control and treatment transects (Tables 2, 3). Observations for all species are in Appendix 3. Total abundance was highest and approximately equal during June and July (Table 2). Bird abundance and species diversity were significantly higher on control segments during May and July, but no other differences between treatment and control segments were significant at the community level in 1991 (Table 3).

Individual Species

Particularly common species during spring migration (May; Appendix 3) included Black-capped Chickadee, Yellow-rumped Warbler, and White-throated Sparrow on treatment segments; Ovenbirds and Black-throated Green Warblers were abundant on controls. Six species (16% of 38 tested) showed a significant difference in abundance between controls and treatments (Table 4); only the White-throated Sparrow was more abundant on controls.

Table 2. Total numbers of individuals and species observed on treatment (T) and control (C) transects in Michigan, 1985-1991. A combined species total for treatment and control segments is in parentheses.

	1985		1986		1987		1988		1989		1990		1991	
	T	C	T	C	T	C	T	C	T	C	T	C	T	C
May:														
Individuals														
species														
	949	1210	775	888	815	939	570	607	847	856	578	778		
	54 (76)	69	50 (67)	62	53 (66)	56	44 (60)	46	65 (76)	65	55 (72)	60		
June:														
Individuals														
species														
	1629	1327	1098	1169	1061	1014	983	1020	877	880	895	907		
	70 (81)	72	60 (74)	68	70 (89)	77	70 (83)	71	66 (81)	71	63 (76)	66		
July:														
Individuals														
species														
	938	978	1136	1258	891	907	994	1039	772	818	892	1104		
	59 (75)	63	68 (81)	73	69 (83)	68	63 (77)	68	65 (75)	54	59 (72)	65		
August:														
Individuals														
species														
	380	478	682	610	564	469	791	551	323	353	558	556		
	53 (61)	46	59 (68)	54	50 (66)	51	62 (69)	52	36 (52)	45	47 (64)	50		
September:														
Individuals														
species														
	402	627	634	501	469	574	505	435	396	489	612	510		
	36 (55)	48	46 (55)	41	46 (60)	47	48 (60)	45	43 (56)	44	43 (51)	44		

Table 3. Mean observations in a 500m segment on control (C) and treatment (T) segments in Michigan, 1985-91; significance of one-way ANOVAs between treatment and control segments is shown for each year. For two-way ANOVAs, T = treatment effect, Y = year effect, and I = interaction. Two-way ANOVAs were calculated with logged segments excluded.

Month	1985		1986		1987		1988		1989		1990		1991		ANOVA		
	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	Y	I
May:																	
Individuals	23.7	30.3	19.4	22.2	20.4	23.5	14.3	15.2	21.2	21.4	21.4	14.5	19.5	19.5	xxx	xxx	xxx
species	9.7	12.9	8.1	10.8	9.5	11.0	7.7	8.2	9.9	11.3	11.3	7.7	9.8	9.8	xxx	xxx	xxx
June:																	
Individuals	40.8	33.3	27.5	29.2	28.3	25.4	24.6	25.5	21.9	22.0	22.4	22.7	22.7	22.7	xxx	xxx	x
species	14.2	14.0	11.1	12.5	12.5	13.1	11.7	12.9	10.4	12.1	10.5	11.7	11.7	11.7	xx	xxx	xxx
July:																	
Individuals	23.5	24.5	28.4	31.5	22.1	22.7	24.9	26.0	19.3	20.4	22.3	27.6	27.6	27.6	x	xxx	xxx
species	9.6	10.4	11.8	14.4	11.1	11.0	10.8	11.8	9.2	9.7	9.7	12.3	12.3	12.3	xxx	xxx	xxx
August:																	
Individuals	9.6	12.0	17.1	15.3	14.1	11.7	19.8	13.8	8.1	8.8	14.0	13.8	13.8	13.8	xxx	xxx	xxx
species	4.6	5.2	7.3	6.7	6.1	5.8	7.7	6.5	4.0	4.5	5.3	6.2	6.2	6.2	xxx	xxx	xxx
September:																	
Individuals	10.1	15.7	15.9	12.5	11.7	14.4	12.6	10.9	9.7	12.2	15.3	12.8	12.8	12.8			x
species	4.0	5.6	5.4	5.1	5.0	5.6	5.0	4.7	4.7	6.0	5.2	5.7	5.7	5.7	x		

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

Table 4. Mean number of individuals per segment for species that showed a significant difference in abundance between treatment (T) and control (C) segments in Michigan in 1991.

Month	Species	T		C
MAY ¹	Yellow-bellied Sapsucker	1.1	*	0.5
	Winter Wren	0.9	*	0.4
	Northern Parula	0.3	*	0.0
	Black-throated Green Warbler	1.4	*	0.3
	Song Sparrow	0.2	**	0.0
	White-throated Sparrow	0.6	*	1.4
JUNE ²	Yellow-bellied Sapsucker	0.4	*	0.1
	Yellow-bellied Flycatcher	0.2	*	0.5
	Least Flycatcher	1.0	*	0.3
	Brown Thrasher	0.0	*	0.2
	Chestnut-sided Warbler	0.4	*	1.3
	Red-winged Blackbird	0.1	*	0.0
JULY ³	Downy Woodpecker	0.2	*	0.0
	Black-capped Chickadee	2.1	**	1.1
	Winter Wren	1.0	**	0.4
	Blackburnian Warbler	0.2	*	0.0
	Mourning Warbler	0.4	*	0.1
	Rose-breasted Grosbeak	0.8	***	0.1
AUGUST ⁴	Downy Woodpecker	0.0	*	0.2
	Blue Jay	0.3	*	0.9
	White-breasted Nuthatch	0.4	*	0.1
	Brown Creeper	0.4	*	0.1
	Cedar Waxwing	0.7	*	2.0
	Common Yellowthroat	0.4	*	0.1
	Chipping Sparrow	0.2	*	0.0
SEPTEMBER ⁵	Winter Wren	0.1	*	0.0
	Black-and-white Warbler	0.1	*	0.0

¹ 38 species tested. * P < 0.05; ** P < 0.01

² 52 species tested.

³ 46 species tested.

⁴ 29 species tested.

⁵ 28 species tested.

The Ovenbird was the most abundant species in June on control and the Nashville Warbler was the most abundant on treatment segments (Appendix 3).

Three species were significantly more abundant on control segments and three on treatment segments (Table 4; 6 significant differences out of 52 species tested; 12%).

Abundant species during July (late breeding) included the Nashville Warbler and Ovenbird on treatment segments and Ovenbirds, Red-eyed Vireos, and Black-capped Chickadees on control segments (Appendix 3). Six species (13% of 46 tested) showed a significant difference in abundance between controls and treatments (Table 4); all were more abundant on treatments.

Cedar Waxwings were common on treatment segments and Black-capped Chickadees were common on both treatment and control segments during July (Appendix 3). Seven species (24% of 29 tested) showed a significant difference in abundance between control and treatment segments (Table 4). Four species were more abundant on treatment segments and three on controls.

Bird communities during late fall migration (September) were dominated by Black-capped Chickadees and Red-breasted Nuthatches (Appendix 3). Only two species, Winter Wren and Black-and-white Warbler, differed in abundance between control and treatment segments (Table 4; 7% of 28 tested); both were more abundant on treatment segments.

Guild Composition

Few significant differences (3 of 25 tests) in abundance of different foraging guilds were noted between treatment and control segments (Table 5). Differences in abundance were significant in May and July for foliage insectivores and in July for

Table 5. Mean number of individuals per segment in foraging and habitat guilds that showed a significant difference (one-way ANOVA) between treatment (T) and control (C) segments in Michigan in 1991.

Guild	Month	T		C
FORAGING GUILDS				
Foliage in.sects	May	6.7	*	8.2
Foliage insects	July	10.3	*	13.2
Bark insects	July	0.6	*	1.3
HABITAT GUILDS				
Deciduous forest	May	4.5	*	7.1
	July	7.3	**	12.9
Mixed forest	May	2.8	*	5.2
Early successional	May	1.8	*	0.9
	June	3.8	*	1.9
	August	2.6	***	1.1

* = P < 0.05

Table 6. Species differing between treatment and control segments in the average change in abundance from pre-impact years (mean of 1986 and 1987) to 1991 (full impact year). Differences were tested with a t-test. Negative values indicate that number of individuals decreased from the pre-impact to full impact year.

Species	Month ¹	Change in abundance per segment		
		T		C
Nashville Warbler	May	-4.22	*	-2.82
Yellow-bellied Sapsucker	June	-0.38	*	0.35
Great Crested Flycatcher	June	0.23	*	-0.43
White-throated Sparrow	June	-1.33	*	-0.50
Rose-breasted Grosbeak	July	-0.29	*	0.88
Downy Woodpecker	August	0.07	**	-0.93
Downy Woodpecker	September	0.07	*	-0.92

¹ Number of species tested: May, 28; June, 35; July, 31; August, 19; September, 18.

* = P < 0.05; ** = P < 0.01.

bark insectivores. In all three cases, birds within these guilds were more abundant on treatment segments.

Differences were slightly more pronounced among habitat guilds (20% or 6 of 30 tests were significant; Table 5). Birds preferring deciduous forest habitats were more common on control segments during May and July. Birds preferring early successional habitats were more abundant on treatment segments during May, June, and August.

AMONG-YEAR COMPARISONS

Considerable annual variation in abundance of individuals and species was noted (Table 3). Abundance has tended to decline during much of this study (Figs. 3, 4), perhaps reflecting the series of droughts that have affected much of the region (see Blake et al. in press), although a slight upturn in numbers was noted in 1991. Although some treatment effects have been noted for individuals during May and for species during May, June, and July (Table 2). Overall, annual variation in abundance and species richness has been considerably greater than variation associated with treatments.

There were few significant differences between treatment and control segments in the average change in abundance of birds from pre-impact years (1986, 1987) to 1991, a full impact year. There were no differences when changes were examined at the community level (total individuals or species) and only 7 when individual species were examined (Table 6). As this represents only 5.3% of the number of species tested, it is no more than might be expected by chance.

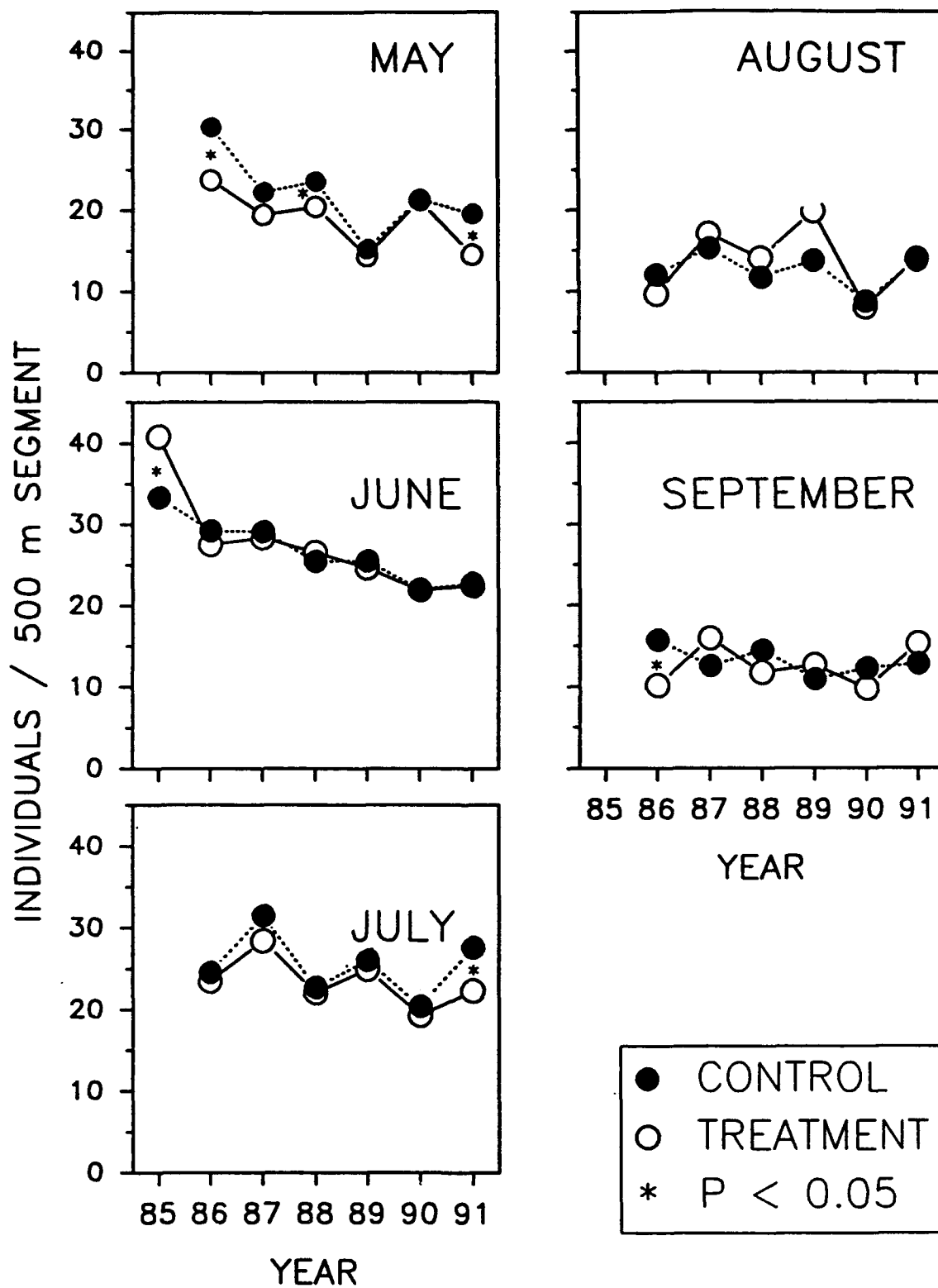


Figure 3. Mean number of individuals recorded per 500 m on treatment and control segments in Michigan.

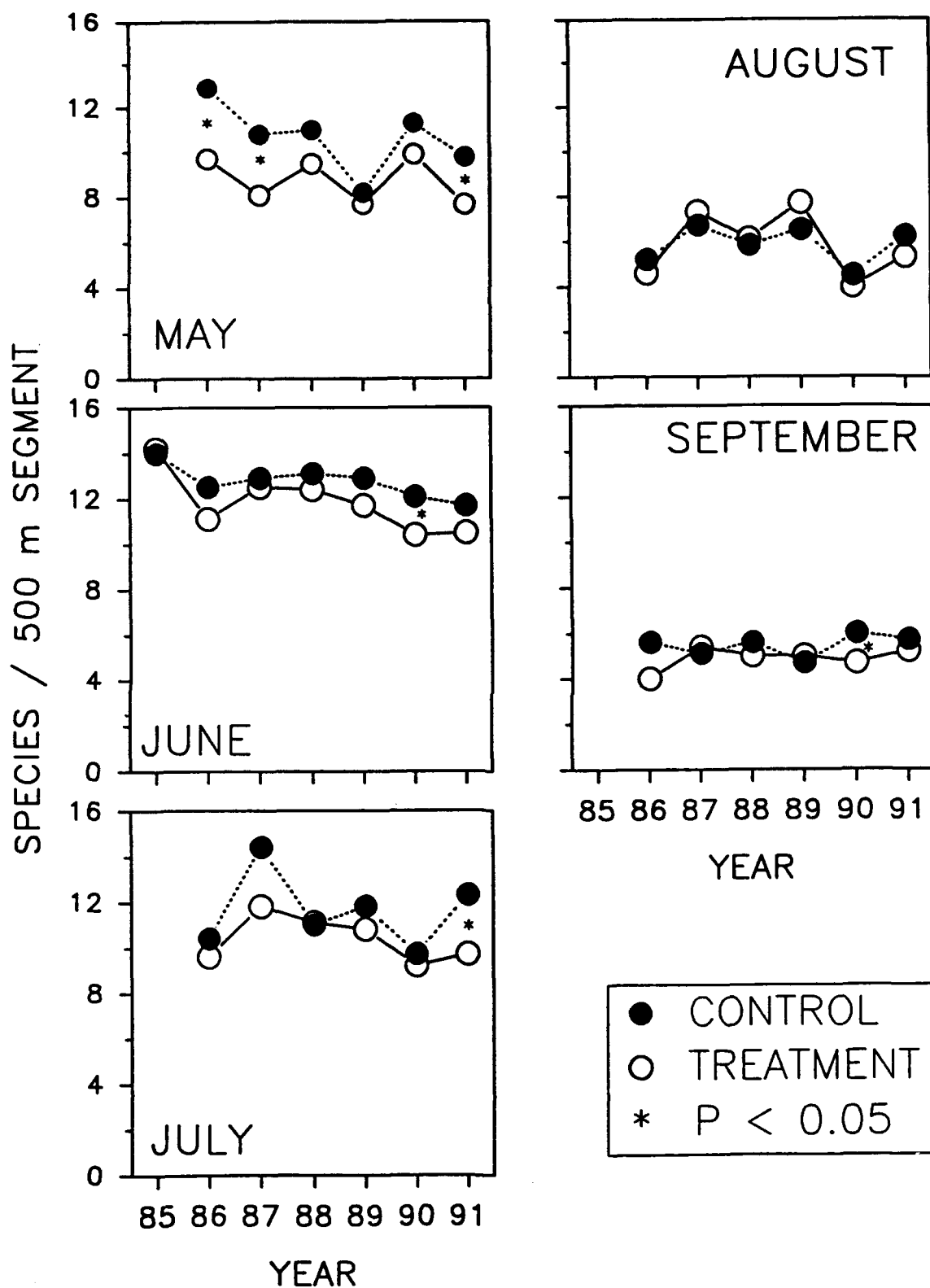


Figure 4. Mean number of species recorded per 500 m on treatment and control segments in Michigan.

DISCUSSION

SPECIES DISTRIBUTION AND ABUNDANCE PATTERNS

No consistent patterns have yet emerged during this study (1985-1991) to demonstrate that distribution patterns of birds are affected by electromagnetic fields produced by ELF antennas in Wisconsin or Michigan (Hanowski et al. 1991, Niemi and Hanowski 1991, this report). Few significant differences in abundance between treatment and control segments have been found at the community or species level; differences that existed in one season or year were not necessarily present in subsequent years or seasons. Differences between treatment and control segments were most noticeable in Michigan during May, both for individuals (Fig. 3) and species (Fig. 4). Apart from May, significant differences in abundance within a single year have been noted three times for number of species (once each in June, July, and September); similar results were noted for individuals). Overall treatment effects (all years combined) tend to be more pronounced for number of species than for individuals; more species per segment typically are recorded on control segments than on treatment segments.

The Michigan facility was operated well below full strength in 1987 and half of 1988 (15 amperes, 8 hr/day, weekdays, starting June 1 1987 through 2 July 1988) and at 75 amperes (8 hr/day, weekdays) for the remainder of 1988 (Appendix 2). It was operated at 150 amperes for 16-24 hr/day during most of the 1989 sampling period and during all of 1990. There has been, however, little noticeable change in bird populations on treatment segments relative to those on control segments. Populations of many species have declined in abundance (e.g., Fig. 5) but declines

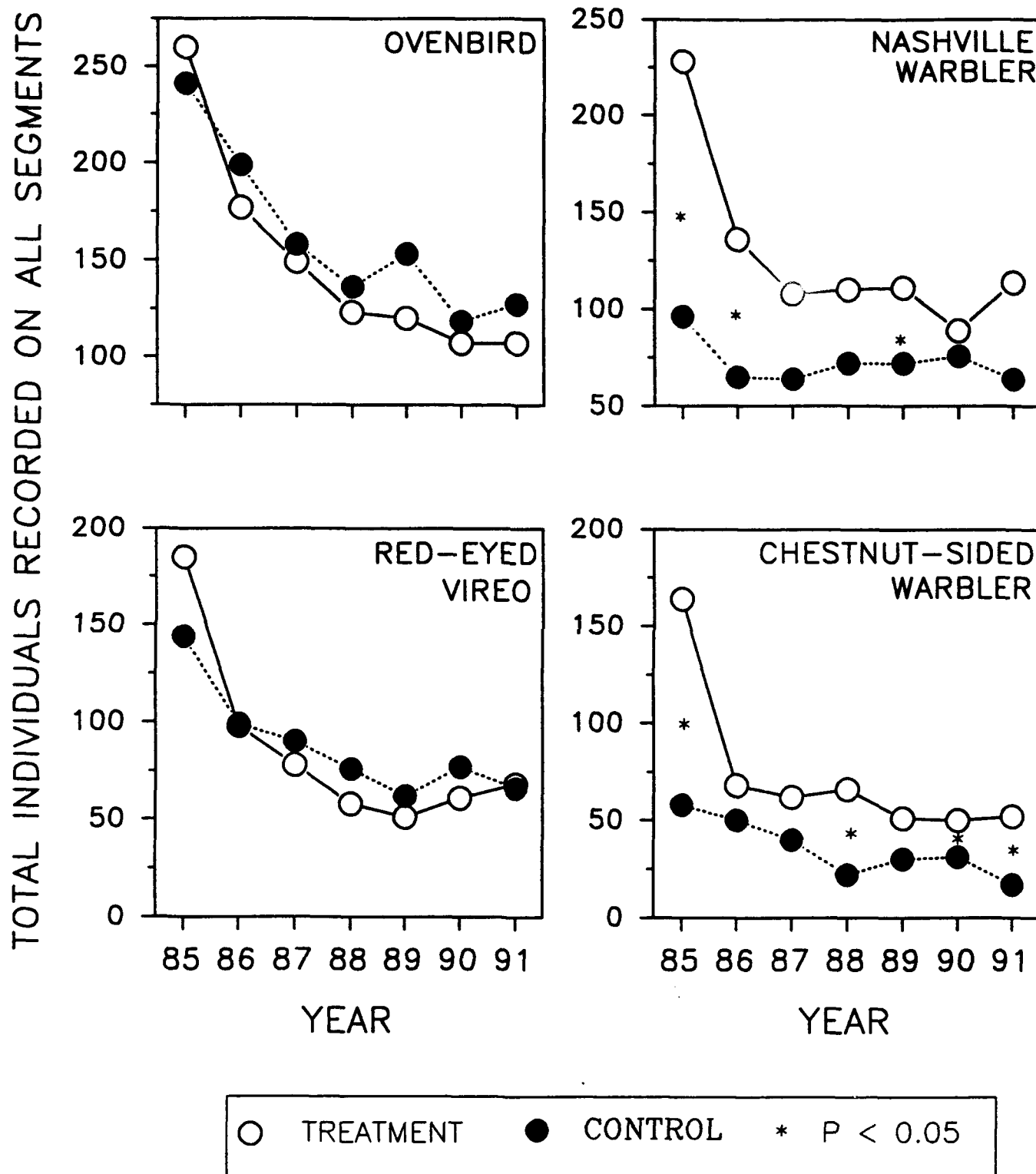


Figure 5. Total number of individuals of four abundant migrants recorded during June on all treatment and control segments in Michigan.

have occurred on both treatment and control segments, often in concert. Further, major declines occurred before the antenna began operation in 1988. Finally, no consistent pattern is yet evident to indicate that changes in abundance on treatment segments have been more pronounced than on control segments since the antenna became fully operational. That is, after the antenna became fully operational in 1989, trends in abundance on treatment and control segments have not been significantly altered.

Results from Wisconsin also showed little consistency among years or seasons in species richness or number of individuals (Hanowski et al. 1991). If the ELF transmitter strongly influenced bird distribution patterns, one might expect that changes in relative abundance of birds on treatment and control segments would be somewhat consistent (within each group) from one year to the next, particularly during the breeding season, and from one season to the next. There was, however, little or no evidence for such a pattern. Species and individuals were more abundant on treatment segments in 1985 and individuals were more abundant on treatment segments in 1986, but no other significant difference at the community level were noted. In fact, throughout 1986-1989, species richness and abundance of individuals were remarkably similar on treatment and control segments in Wisconsin (Hanowski et al. 1991).

GUILD DISTRIBUTION PATTERNS

Species that belong to the same "guild" share some biological characteristics. Thus, if the ELF antenna system influenced the distribution patterns of birds, we might expect members of a particular guild to be influenced in a similar fashion. Similarly, habitat related effects may be evident from the distribution patterns of guild members.

Relatively few differences in abundance of birds in different guilds were noted between treatment and control segments in Michigan in 1991 or either state in previous years (Blake et al. 1991, Hanowski et al. 1991). Differences that did exist likely reflected differences in habitat that exist between treatment and control segments. Treatment segments in Michigan have more early successional habitats than do control areas and birds breeding in such habitats showed the strongest treatment effect, being more abundant on treatment segments (e.g., Chestnut-sided Warbler, Fig. 5). A similar result was noted for earlier years (Blake et al. 1991). Deciduous forest habitat is more common in control areas and coniferous habitats more common in treatment segments in both states (Blake et al. 1988); distribution of birds preferring deciduous habitat followed a similar trend.

INDIVIDUAL SPECIES

Habitat or EM related differences that exist between treatment and control segments may not influence all bird species in the same manner. If some species are more abundant on control and others on treatment segments, then such differences might cancel each other, producing nonsignificant results at the community level. If differences between treatment and control segments (either related to habitat or EM fields) are primary factors influencing distribution patterns of individual species, then we might expect those species to show similar patterns among years and seasons.

There have, however, been relatively few cases where differences in abundance of a species between treatment and control segments have remained consistently significant among seasons and years in Michigan (Table 7; Fig. 5). A total of 50 species in Michigan have shown a significant difference in abundance between

Table 7. Number of years per month^a (1986 - 1991; 1985 - June only) that species were significantly (Kruskal Wallis test) more abundant on treatment or control segments.

Species	More on treatment					More on control				
	M	Ju	Jy	A	S	M	Ju	Jy	A	S
American Woodcock					1					
Northern Flicker	1	1								
Yellow-bellied Flycatcher		3								
Gray Jay				2						
Golden-crowned Kinglet		1	2	1	1					
Hermit Thrush	1		1							
American Robin			1	2						
Brown Thrasher		2								
Solitary Vireo		1								
Nashville Warbler		3	3							
Chestnut-sided Warbler		4	2							
Yellow-rumped Warbler	1	2								
Rufous-sided Towhee		1								
White-throated Sparrow	1	5	2	1	2					
Dark-eyed Junco	2									
<hr/>										
Ruffed Grouse		1								1
Downy Woodpecker				1		1		1		1
Blue Jay				1		1			1	
Cedar Waxwing				2			1			
Mourning Warbler		1						1		
Indigo Bunting				1			1		1	
Chipping Sparrow		2				1			1	
Song Sparrow	2	1		1		1				
<hr/>										
Yellow-bellied Sapsucker						5	2	3	2	1
Hairy Woodpecker							1			
Eastern Wood-Pewee									1	
Least Flycatcher							1	1		
Great Crested Flycatcher						1	3	2		
Black-capped Chickadee						1	1	1		
Red-breasted Nuthatch										1
White-breasted Nuthatch								2	1	
Brown Creeper						2		1	1	
Winter Wren						3	3	1		1
Sedge Wren								1		
Veery								1		
Red-eyed Vireo								1		1
Northern Parula						3	1	1		

Table 7 (continued).

Species	More on treatment					More on control				
	M	Ju	Jy	A	S	M	Ju	Jy	A	S
Black-throated Green Warbler						2	1			
Blackburnian Warbler								1		
Black-and-white Warbler						3				1
Ovenbird						3		2		
Common Yellowthroat							2	1	1	
Canada Warbler							1			
Scarlet Tanager							1	1		
Rose-breasted Grosbeak						1	2	1		
Swamp Sparrow						1		1		
Red-winged Blackbird						2	5	3		
Common Grackle							1			
Brown-headed Cowbird						1	2			
Purple Finch						1				
Number of species	6	14	6	9	3	18	17	20	8	7
Number significant differences	8	28	11	12	4	33	29	27	9	7

^a M = May; Ju = June; Jy = July; A = August; S = September.

treatment and control segments in at least one season and year. Somewhat more species (27) were more abundant on control than on treatment segments (15) (Table 7). However, 12 species have shown a significant difference in only one season in one year (Table 7) and eight species have been more abundant on treatment segments in one season and on control segments in another. For example, the Chipping Sparrow was more abundant on treatment segments during June in two years but was more common on control segments during May and August in other years. Such changes in distribution may reflect seasonal changes in habitat selection. For example, a species may breed in one habitat but then move into a different habitat following breeding. If distribution of breeding and nonbreeding habitats differ between treatments and controls, a switch in abundance between treatment and controls also may occur.

Several species have shown a more consistent pattern of distribution between treatment and control segments. White-throated Sparrows, for example, have been consistently more abundant on treatment segments, particularly in June (Table 7). Chestnut-sided and Nashville Warblers also have been consistently more abundant on treatment segments (Fig. 5). Several species (e.g., Yellow-bellied Sapsucker, Winter Wren, Ovenbird [Fig. 5], and Red-winged Blackbird) consistently have been more abundant on control segments.

Differences in abundance of species that showed a consistent difference between treatment and control segments likely are related to habitat in many cases. White-throated Sparrows, for example, favor early successional habitats. Such habitats were more common on treatment segments than on controls in Michigan. In

contrast, deciduous woods are more common on control segments and Yellow-bellied Sapsuckers, which prefer deciduous forests, were more frequently observed on control segments.

If the antenna operation adversely affected bird species, we might have expected the number of species more abundant on treatment segments to decline after operation began. Birds have been sampled during all five months since 1986. Both 1986 and 1987 can be considered pre-impact years (although the antenna was tested at low power during part of 1987). The antenna was tested at half strength during 1988 and was at full strength during most of 1989 and all of 1990 and 1991 (Appendix 2). Thus, we consider 1988 a transitional year and 1989 - 1991 as impact years. During 1986-1987, species were significantly more abundant on treatment segments in 18 instances and more abundant on control segments 35 times (Fig. 6). (We are not including 1985 here as samples were collected only during June.) During 1989-1991, species were more abundant on treatment segments 24 times and 51 times on controls. Thus, a similar proportion of significant differences were noted for species more abundant on treatment segments both before (34%) and after (32%) antenna operation reached full strength. The difference in distribution between the pre- (1986-1987) and post-impact (1989-1991) periods was not significant (comparing number of species more abundant on treatment or control segments during each of the two periods [i.e., pre- and post-impact]; $\chi^2 = 0.05$, $P > 0.80$, 1 df). Similarly, if the distribution of significant differences is compared among all years, no difference exists among years ($\chi^2 = 3.59$, $P > 0.60$, 5 df). The increase from 1987 to 1988 in number of species more abundant on treatment segments (Fig. 6) may reflect the effect of the

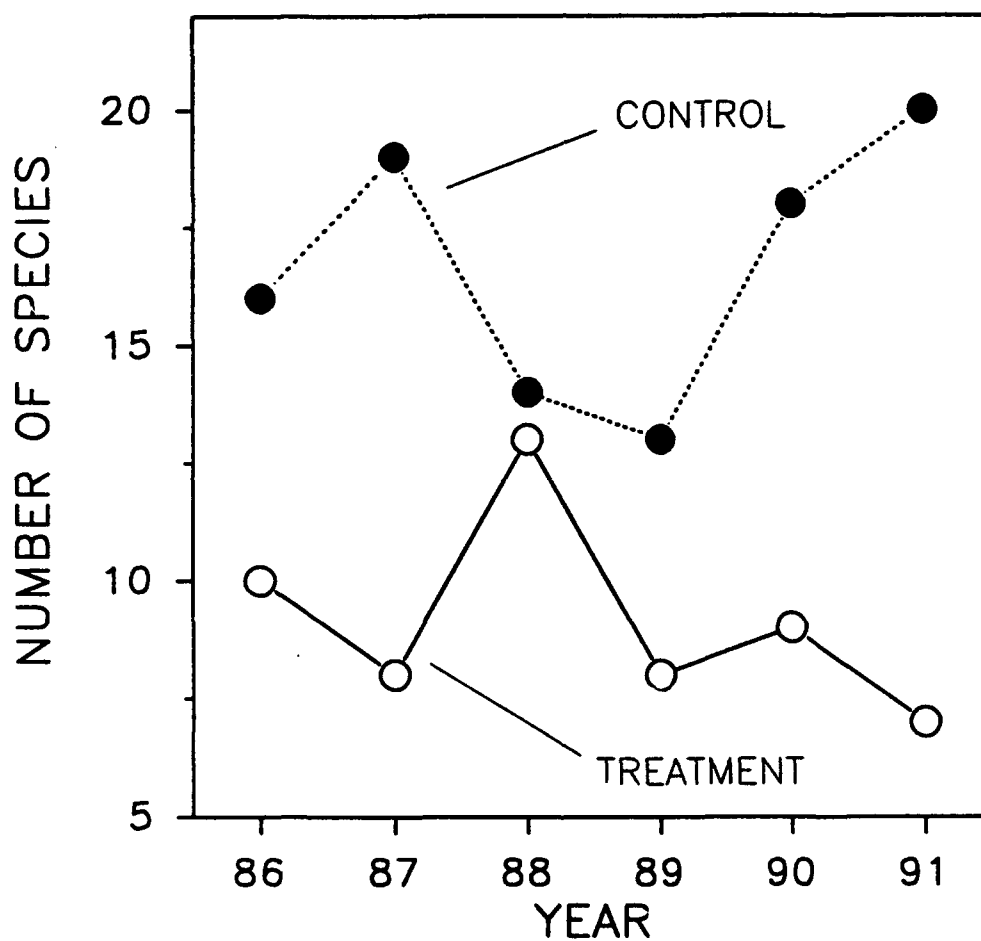


Figure 6. Number of cases per year when species were significantly more abundant on treatment or control segments in Michigan.

1988 drought (Blake et al. in press). Lowland (i.e., wet) habitats are more common on treatment segments than on controls and such habitats may have provided a refuge for birds, particularly in relation to the drier upland habitats more common in control areas.

Number of species more abundant on control or treatment segments also showed little consistency over time when examined among years by month (Fig. 7). (August and September were omitted because too few differences were noted.) This was particularly true during June, the main breeding period, when effects of antenna operation should be most strongly felt (i.e., because birds are strongly tied to territories and are less apt to wander).

OBJECTIVES

Our major objectives for 1991 were to complete bird censuses during all seasons, to initiate comparisons based on pre- and post-impact data, and to complete this annual report. Additionally, several manuscripts derived from previous work have been submitted for publication or are in preparation (Appendix 4). Our objectives for 1992 and beyond are to continue our sampling of bird communities in Michigan, following our established procedures.

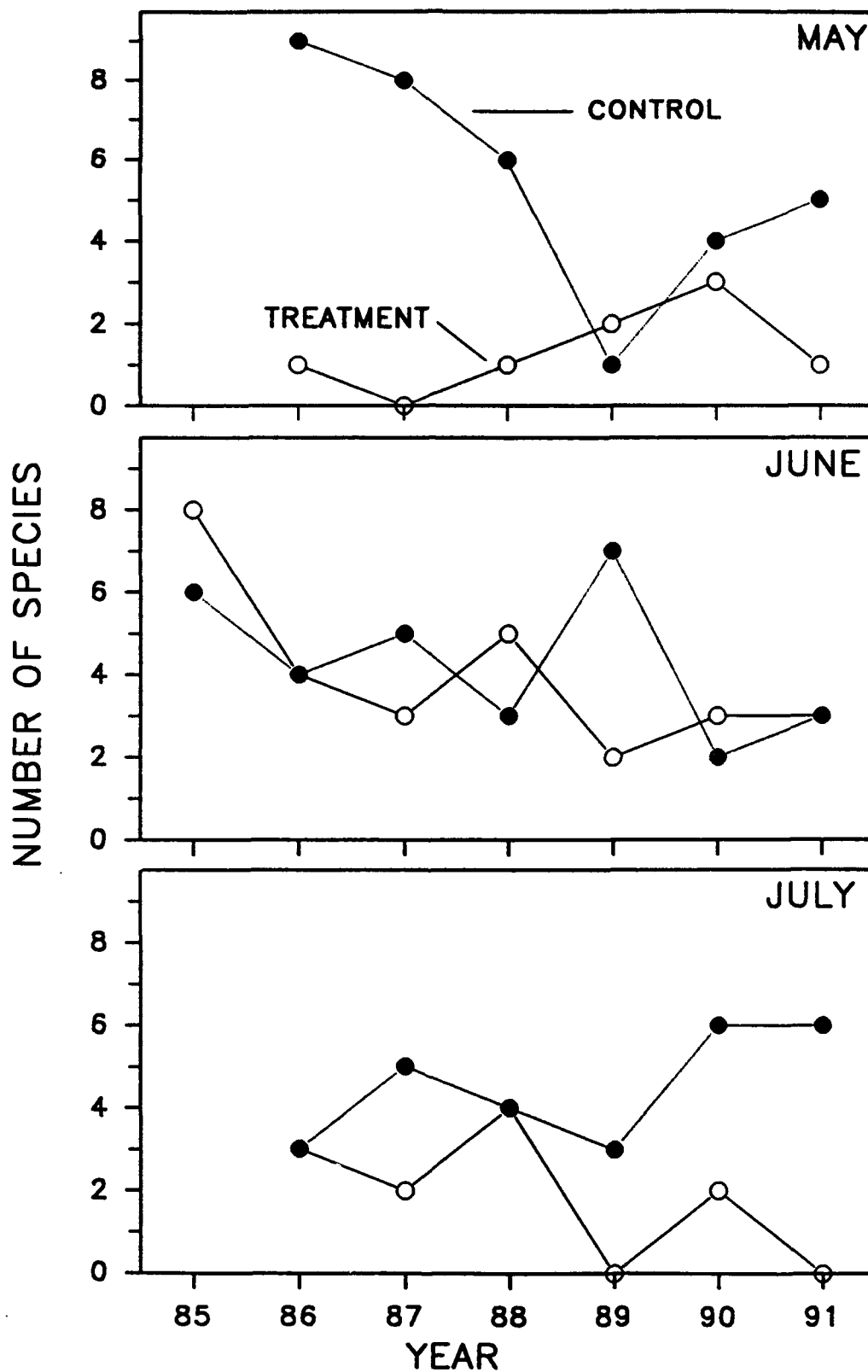


Figure 7. Number of species significantly more abundant on Michigan treatment or control segments during May, June, and July, 1985-1991.

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Appendix 1. Nesting, feeding, habitat, and migration classification for bird species observed in Michigan and Wisconsin.

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Appendix 1. Nesting, feeding, habitat, and migration classification for bird species observed in Michigan and Wisconsin.

Species	Nesting	Food	Habitat	Migration
Common Loon	1	1	9,8	2
Pied-billed Grebe	1	1	9,8	2
American Bittern	3	1	6,9	2
Great Blue Heron	2	1	9,1,2,3	2
Wood Duck	4	18	9,1	2
Mallard	1	18	9,8	2
Blue-winged Teal	1	18	9,8	3,2
Turkey Vulture	1	3	3,1,5	2,3
Osprey	2	1	9,3	2,3
Bald Eagle	2	1	9,3	2,1
Northern Harrier	1	2	8,5,10	2,3
Sharp-shinned Hawk	2	2	2,3,11	2
Cooper's Hawk	2	2	1,3	2
Northern Goshawk	2	2	2,3	4,1
Broad-winged Hawk	2	2	3,1	3
Red-tailed Hawk	2	2	5,1	2
American Kestrel	4	2	5,4	2,3
Spruce Grouse	1	4	2,11	1
Ruffed Grouse	1	4	1,3,4	1
Virginia Rail	3	19	6,8	2

Appendix 1 (continued)

Species	Nesting	Food	Habitat	Migration
Sora	3	19,18	8,6	2
Sandhill Crane	1	5	8,5,10	2
Solitary Sandpiper	2,3	19	9	3
Spotted Sandpiper	1	19	9	2,3
Common Snipe	1	19	8,6,5	2
American Woodcock	1	6	6,5,4,1	2
Mourning Dove	2,3	7	5,7	2
Black-billed Cuckoo	3	10	1,4,6	3
Yellow-billed Cuckoo	3	10	1,4,6	3
Great Horned Owl	2	2	3,2,1	1
Barred Owl	2	2	1,3	1
Common Nighthawk	1	11	3,7,4	3
Whip-poor-will	1	11	1,3,4	2
Chimney Swift	4	11	7,3,1	3
Ruby-throated Hummingbird	2	17	5,7,4	3
Belted Kingfisher	4	1	9	2
Yellow-bellied Sapsucker	4	17,16	1,3,2	2
Downy Woodpecker	4	16	1,4,3	1
Hairy Woodpecker	4	16	1,3,4	1
Black-backed Woodpecker	4	16	2,11,3	1
Northern Flicker	4	9	1,3,2	2

Appendix 1 (continued)

Species	Nesting	Food	Habitat	Migration
Pileated Woodpecker	4	16	1,3,2	1
Olive-sided Flycatcher	2	12	4,11,2	3
Eastern Wood-Pewee	2	12	3,1,2	3
Yellow-bellied Flycatcher	1	12	11,2	3
Alder Flycatcher	3	12	6	3
Least Flycatcher	2	12	1,3,4	3
Eastern Phoebe	5	12	9,7	2
Great Crested Flycatcher	4	12	1,3	3
Eastern Kingbird	2,3	12	5,4,10,8	3
Tree Swallow	4	11	5,7,4,9	2,3
Gray Jay	2	5	11,3,2	1
Blue Jay	2	5	1,3,2	1
American Crow	2	5	5,1,3,7	2,1
Common Raven	2	5	2,3,7	1
Black-capped Chickadee	4	10	1,3,11,2	1
Boreal Chickadee	4	10	11,2	1
Red-breasted Nuthatch	4	16	2,3,11,1	1
White-breasted Nuthatch	4	16	1,3	1
Brown Creeper	4	16	1,3,2,11	2,1
House Wren	4	10	7,4	2
Winter Wren	1,6	10	3,11,4,2	2

Appendix 1 (continued)

Species	Nesting	Food	Habitat	Migration
Sedge Wren	3	10	8,6,5	2
Marsh Wren	3	10	8	2
Golden-crowned Kinglet	2	10	2,11	2,1
Ruby-crowned Kinglet	2	10	2,11,4,6	2
Veery	1	9	1,4,3,6	3
Gray-cheeked Thrush	3	9	4,11,2	3
Swainson's Thrush	2,3	9	11,2,4	3
Hermit Thrush	1	9	3,11,1,2	2
Wood Thrush	3,1	9	1,3	3
American Robin	2,3,1	9	5,7,4,1	2,1
Gray Catbird	3	13	4,6,7	2,3
Brown Thrasher	3	9	4,7	2
Bohemian Waxwing	2	14	4,3,1	4
Cedar Waxwing	2	14	4,3,1	1,2
European Starling	4	9	7,3	1
Solitary Vireo	2	10	3,11,2	3,2
Yellow-throated Vireo	2	10	1,3	3
Warbling Vireo	2	10	4,3,1	3
Philadelphia Vireo	2,3	10	1,3,6	3
Red-eyed Vireo	2,3	10	1,3,4	3
Golden-winged Warbler	1,3	10	4,6	3

Appendix 1 (continued)

Species	Nesting	Food	Habitat	Migration
Tennessee Warbler	1	10	3,2,6,4	3
Orange-crowned Warbler	1	10	6,4,3	2,3
Nashville Warbler	1	10	3,4,11,2	3
Northern Parula	2	10	11,3,2	3
Yellow Warbler	3	10	6,5,7	3
Chestnut-sided Warbler	3	10	4,3	3
Magnolia Warbler	2,3	10	4,2,3	3
Cape May Warbler	2	10	2,3	3
Black-throated Blue Warbler	3	10	1,3,4	3
Yellow-rumped Warbler	2	13	2,3,11,4	2,3
Black-throated Green Warbler	2	10	3,1	3
Blackburnian Warbler	2	10	2,3	3
Pine Warbler	2	10	2	2
Palm Warbler	1	6	11,10	2,3
Bay-breasted Warbler	2	10	2,3	3
Blackpoll Warbler	2	10	2,4,3	3
Black-and-white Warbler	1	16	3,4,6,1	3
American Redstart	2,3	12,10	4,1,6	3
Ovenbird	1	6	1,3,2,4	3
Northern Waterthrush	1,6	6	9	3
Connecticut Warbler	1	10	11	3

Appendix 1 (continued)

Species	Nesting	Food	Habitat	Migration
Mourning Warbler	1,3	10	4,3	3
Common Yellowthroat	3	10	6,8,4	2,3
Wilson's Warbler	3	10	6	3
Canada Warbler	3	10	3,4	3
Scarlet Tanager	3	10	1,3	3
Rose-breasted Grosbeak	3,2 13	1,4,3	3	
Indigo Bunting	3	15	5,4	3
Rufous-sided Towhee	1,2,3	8	4	2
American Tree Sparrow	3	7	5	4,2
Chipping Sparrow	2	8	2,3,4,11	2
Clay-colored Sparrow	3	8	5,6	2,3
Field Sparrow	1,3	8	5	2
Savannah Sparrow	1	8	5,8,10	2
Fox Sparrow	1,3	8	4,5	2
Song Sparrow	3	8	5,4,6	2
Lincoln's Sparrow	1	8	10,8,4	2
Swamp Sparrow	3	8	6,8	2
White-throated Sparrow	1	8	4,3,2,11,1	2
White-crowned Sparrow	1,3	8	4,6,5	2
Dark-eyed Junco	1	8	11,2,3,4	2,1
Snow Bunting	5	7	5	4

Appendix 1 (continued)

Species	Nesting	Food	Habitat	Migration
Bobolink	1	8	5,8	3
Red-winged Blackbird	3	8	8	2
Eastern Meadowlark	1	6	5	2
Western Meadowlark	1	6	5	2
Yellow-headed Blackbird	3	8	8	2
Rusty Blackbird	3	8	9	2
Brewer's Blackbird	3,1	8	5	2
Common Grackle	3	5	5,9,7	2
Brown-headed Cowbird	7	8	5,4,1,7	2
Northern Oriole	2	13	1,3	3
Pine Grosbeak	2	7	2,11	4
Purple Finch	2	7	3,2,4	2,1
Red Crossbill	2	7	2,11,3	4,1
White-winged Crossbill	2	7	2,11,3	4,1
Common Redpoll	3	7	5	4
Hoary Redpoll	3	7	5	4
Pine Siskin	2	15	2,3	1,4
American Goldfinch	3,2	7	5,6,4	2
Evening Grosbeak	2	15	3,2,7	1,4
House Sparrow	4	7	7	1

Appendix 1 (continued)

A. Nesting

- 1 Ground
- 2 Canopy or canopy vegetation (tree but not necessarily tree top)
- 3 Subcanopy or shrub
- 4 Cavity, hole or bank
- 5 Ledge or platform
- 6 Cavity - tree roots
- 7 Nest parasite

B. Food

- 1 Aquatic vertebrates, including fish or other aquatic vertebrates
- 2 Birds, small mammals, large insects
- 3 Carrion
- 4 Vegetation such as buds, pine needles, and seeds but excluding species concentrating on seeds or fruits
- 5 Various small vertebrates (including eggs and young), invertebrates, plants, carrion, etc. (e.g., Omnivores)
- 6 Ground invertebrates
- 7 Seeds (plus a smaller amount of fruit by some species)
- 8 Ground invertebrates and seeds
- 9 Ground invertebrates and fruit
- 10 Foliage invertebrates
- 11 Aerial insects - taken while in continuous flight
- 12 Aerial insects - taken in sallies from a perch

Appendix 1 (continued)

- 13 Foliage invertebrates and fruit
- 14 Fruit
- 15 Foliage invertebrates and seeds
- 16 Bark insects
- 17 Nectar and sap
- 18 Aquatic vegetation
- 19 Aquatic invertebrates

C. Habitat

- 1 Deciduous forest
- 2 Coniferous forest
- 3 Mixed deciduous - coniferous forest
- 4 Early successional deciduous - coniferous forest
- 5 Fields and meadows
- 6 Shrub swamp
- 7 Urban
- 8 Open wetlands (e.g., sedge fen, cattail)
- 9 Ponds, lakes, rivers, and streams
- 10 Muskeg
- 11 Lowland coniferous forest

D. Migration

- 1 Permanent resident; populations may be augmented during winter or during summer

Appendix 1 (continued)

- 2 Short-distance migrant; generally includes breeders; individuals generally winter south of study areas but most winter north of the tropics
- 3 Long-distance migrant; generally winter south of the U.S.
- 4 Winter resident

Appendix 2. ELF Communications System Ecological Monitoring Program: Breeding and Migrating Birds. Technical Summary.

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ELF COMMUNICATIONS SYSTEM ECOLOGICAL MONITORING PROGRAM:

BREEDING AND MIGRATING BIRDS

TECHNICAL SUMMARY

SUBCONTRACT NUMBER: E06595-88-C-011

Submitted to:

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ELF Communications Program
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The University of Minnesota is an equal opportunity employer.

1. TECHNICAL SUMMARY

Pre and post-antenna operational data base

Our investigation to determine effects of ELF electromagnetic fields began in Michigan in late summer of 1984. Data were collected during the fall migration period in 1984 to test methods and assess adequacy of sample size. We do not include these data in statistical analyses because several of the study areas were changed between 1984 and 1985 due to unsuitable electromagnetic field ratios between control and treatment areas (Brosh et al. 1986). Breeding bird (June) data were gathered in existing study areas in 1985. In 1986 we expanded the scope of the study to include migrating birds. We have gathered data during spring migration (May), breeding (June), late-breeding (July), early fall migration (August), and late fall migration (September) since 1986.

Based on antenna operation and testing data, we have one year of true pre-operational data (1985 breeding season). The antenna was tested for short periods of time at low power in 1986 (4-6 amps) and in 1987 (15 amps) (Figure 1). The duration of operation and power was increased in 1988 (75 amps) and in 1989 the antenna was operated at full power (150 amps) (Figure 1). Magnitudes of 76 Hz longitudinal electric fields and 76 Hz magnetic flux densities measured at our control and treatment study areas reflect the level of power at which the antenna was operated (Figure 2). Exposures in 1986 and 1987 were similar in terms of duration and magnitude and there was an order of magnitude change in both electric and magnetic fields between 1987 and 1988 when the power was increased from 15 to 75 amps (Figure 2). The EM exposure criteria set at the beginning of the project specified that control and treatment exposures must differ by

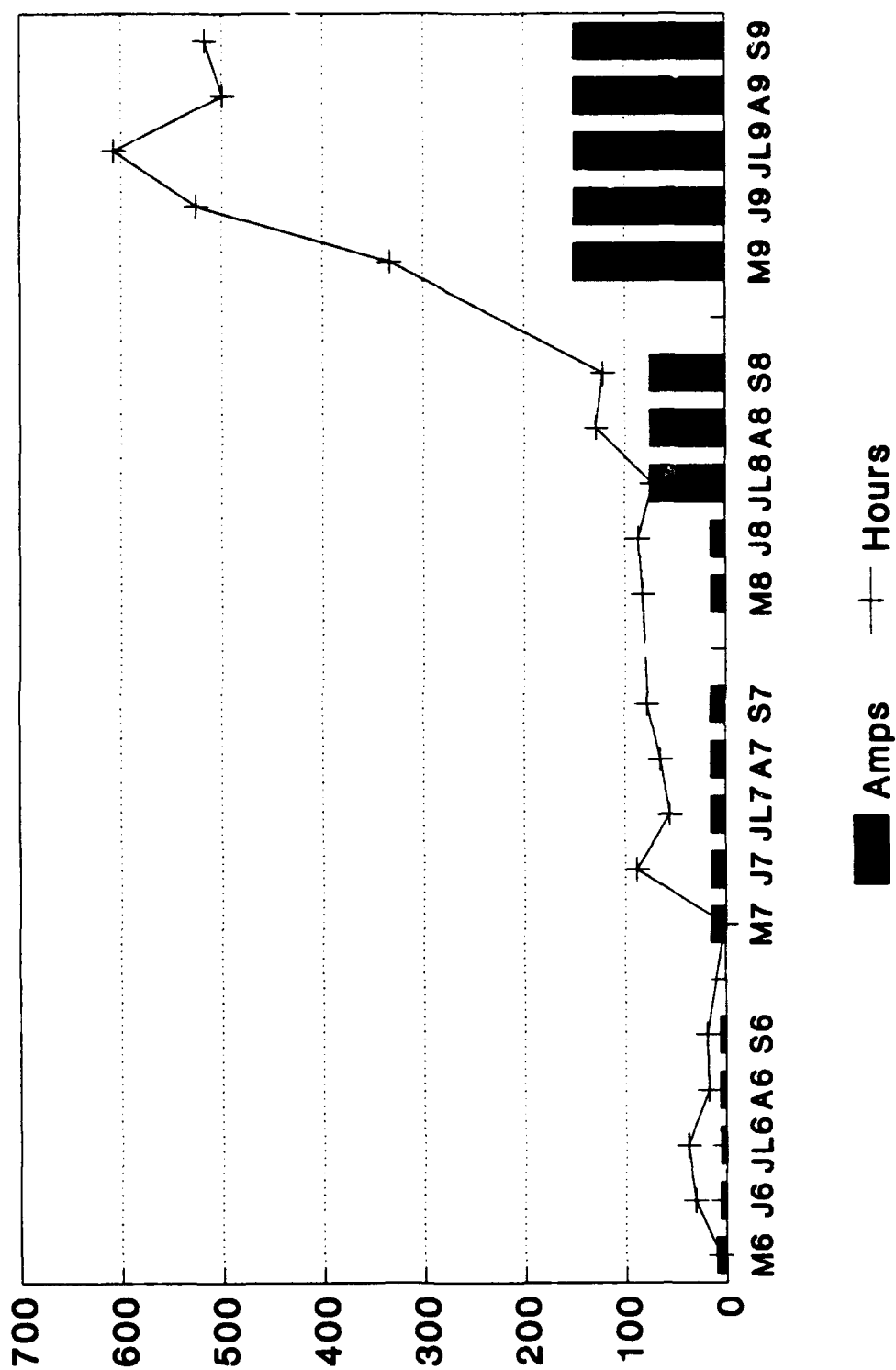
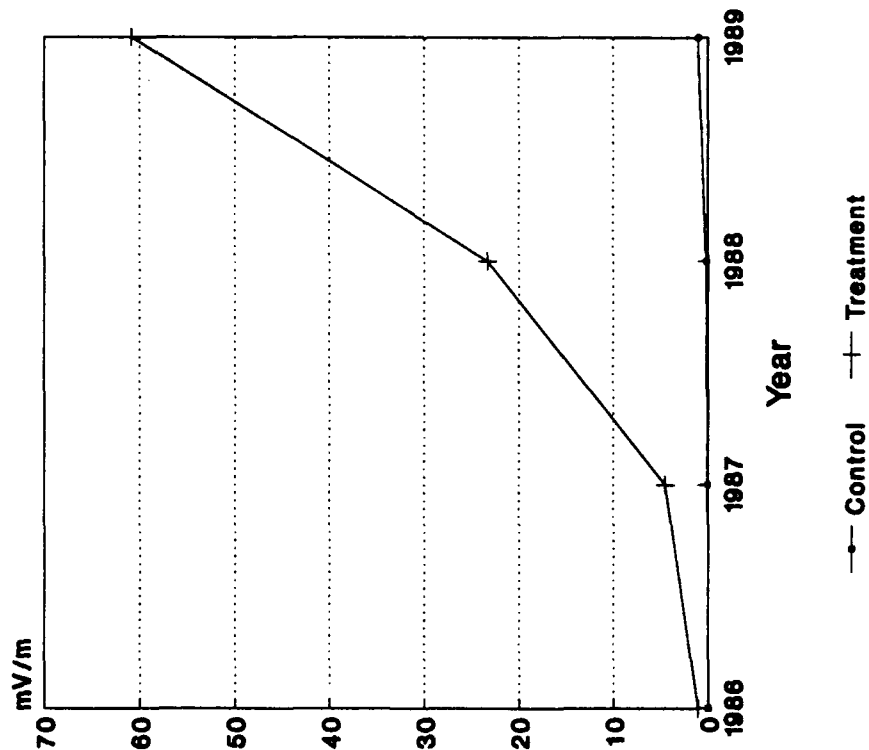


Figure 1. Power (amps) of operation and number of hours antenna was operated in each month (M = May; J = June; JL = July; A = August; S = September) from 1986 (6) to 1989 (9) in Michigan.

76 Hz Longitudinal Electric Fields



76 Hz Magnetic Flux Densities

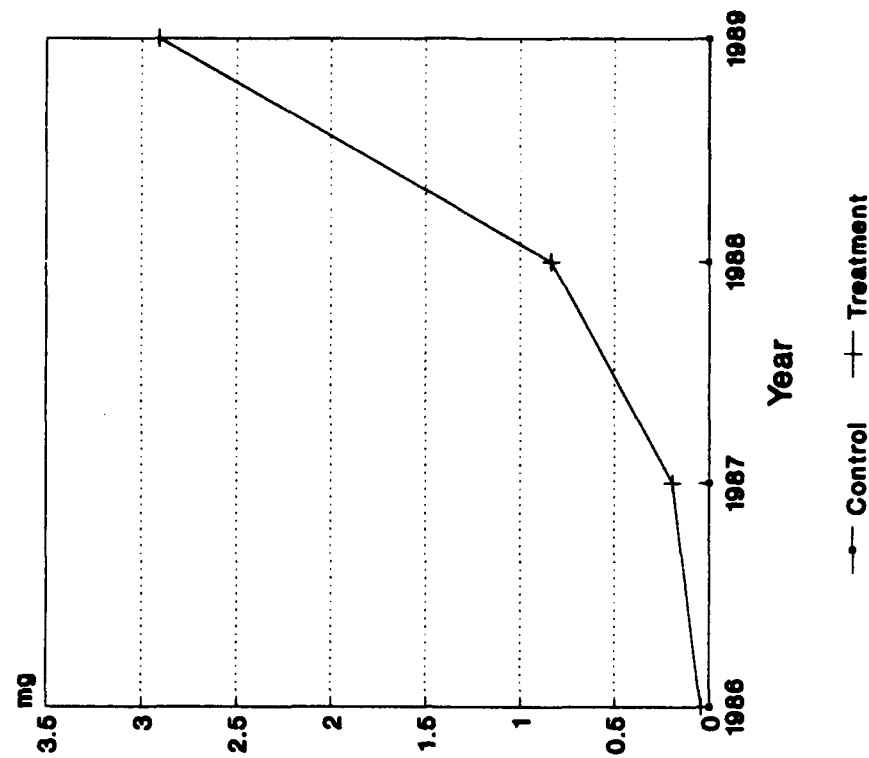


Figure 2. Electromagnetic field magnitudes measured in control and treatment study areas from 1986 to 1989.

an order of magnitude. Therefore, because there was an order of magnitude change in EM field exposure between 1987 and 1988 we consider 1986 and 1987 as pre-full operational data, 1988 as transitional, and 1989, 1990, and 1991 as post-full operational data.

Statistical model for pre and post-operational comparisons

We are testing the hypothesis that there is no difference in the magnitude and direction of change in control versus treatment study areas between the pre-full operational years and post-full operational years for bird species and community parameters. The before-and-after statistical model (Equation 1) that we used to test the hypothesis calculates the difference between each post-operational (post_i) year and the mean of the pre-operational years (pre_{x86,87}).

$$\text{Equation 1. } \Delta = \text{post}_i - \text{pre}_{x86,87}$$

This difference (Δ) is calculated for each 500 m transect and the mean difference among control (Δ C) and mean difference among treatment (Δ T) transects is compared with a t-test (two-tailed).

This model is preferred over a standard t-test or two-way ANOVA (treatment and year) that tests for differences in mean number of individuals in control and treatment transects in each year because it directly tests the null hypothesis (e.g., there is no difference in Δ C and Δ T in pre and post-operational years between control and treatment areas). A t-test or two-way ANOVA using mean values would not allow us to separate inherent differences between control and treatment (e.g., due to habitat) from EM field induced changes. For example, we observed differences in bird parameters between control and treatment areas before the antenna was operated (June 1985). Differences in

mean values between control and treatment were attributed to differences in habitat between control and treatment areas. Because these differences in habitat are still present after the antenna has become operational, a t-test or two-way ANOVA for any bird parameter that showed a difference prior to antenna operation would not allow us to test for EM exposure effects in subsequent years. In contrast, a test that compares changes in numbers of birds between control and treatment study areas controls for initial differences in habitat and subsequent differences in bird abundance between study areas when the antenna became operational.

Variable selection

The following parameters were selected for testing with the before-and-after design: (1) total number of individuals / 500 m transect; (2) total number of species / 500 m transect; (3) numbers of individuals / 500 m transect within each habitat, feeding, nesting, and migration guild; and (4) number of individuals / 500 m transect for those species that occur on at least 25% of (10 of 40) control or treatment transects in one year.

Differences between pre and post years for individual species are not computed for transects where the species was not present in both pre and post years. This was done to eliminate zero difference values (e.g, $0 - 0 = 0$) from the calculation of mean differences. Including zero values would result in a lower mean of the differences and would be influenced by the number of study areas where the species did not occur. Zero values are included for species that are present in either pre or post years.

Power of statistical tests

We used the formula presented by Lehmann and D'Abrera (1975) to calculate the power of a t-test. We used the mean change in control (ΔC) and treatment (ΔT) (each

post-year minus mean of pre-years) values in these analyses. We present data for community parameters (number of individuals and species), the three most abundant guild categories for migration, nesting, feeding, and habitat, and the most abundant individual bird species for each month (May to September). Sample size, mean, and coefficient of variation values presented are the mean values of control and treatment study areas in 1988, 1989, and 1990. Sample sizes reported in the tables are the mean number of study areas where the species occurred in 1988, 1989, and 1990 (Tables 1 to 5).

Power of t-tests (two-tailed) are presented for levels of change in terms of number of birds. For example, a power of 0.83 for American Robin in May for change of one bird indicates that we would have an 83% chance of detecting a difference in change between control and treatment of one bird. Therefore, if abundance of this species changed from 2.1 (pre-operational) to 1.1 (post-operational) on treatments and did not change (e.g., pre and post-operational difference = 0) in control areas the t-test would indicate a significant difference for this bird ($P < 0.05$). The power for each variable is in bold in the tables when it reaches or exceeds 0.80. This is the value used by our statistical tests when determining if the difference between control and treatment study areas is significant ($\alpha 0.05$).

The difference in power in terms of change in number of birds for each group of variables primarily reflects the magnitude of the variance of the variable. For example, the mean value for total number of individuals is highest and the power of 0.80 is not reached until there is a difference of five or more birds between control and treatment areas. Variance values for individual species are lower and a power of 0.80 is reached when there is a difference in change between control and treatments of one or two birds.

Table 1. Mean (control and treatment 1988, 1989, 1990), coefficient of variation, sample size (mean of segments where individual occurred over 3 years), and power of t-test (two-tailed) based on the difference between post- and pre-operational antenna bird parameters for May. Transects with zero counts during pre and post years are not included. Logged sites were also excluded. For example, the power of detecting a difference in post- and pre-operational numbers of one American Robin individual between control and treatment study areas is 0.83 (if such a difference exists).

Parameter	N	Mean	CV	Change in number of individuals (post-pre)					
				0.5	1	2	3	4	5
Total individuals	70.00	18.97	46.50	0.04	0.07	0.17	0.33	0.53	0.72
Total no. species	70.00	8.59	41.23	0.10	0.26	0.80	0.98	1.00	1.00
Permanent resident	69.67	4.08	68.76	0.10	0.29	0.80	0.99	1.00	1.00
Short distance migrant	70.00	10.54	60.45	0.06	0.11	0.32	0.60	0.84	0.96
Long distance migrant	70.00	3.75	150.01	0.08	0.18	0.56	0.88	0.99	1.00
Ground nests	70.00	5.82	79.04	0.07	0.16	0.48	0.81	0.97	1.00
Canopy nests	70.00	6.25	61.94	0.07	0.15	0.46	0.80	0.96	1.00
Subcanopy nests	60.00	1.72	164.06	0.10	0.28	0.80	0.98	1.00	1.00
Ground ins. & seeds	66.33	2.81	123.16	0.09	0.24	0.80	0.97	1.00	1.00
Foliage insects	70.00	7.62	62.99	0.06	0.14	0.42	0.80	0.94	0.99
Ground invertebrates	69.33	3.05	76.83	0.12	0.36	0.89	1.00	1.00	1.00
Deciduous habitat	69.67	5.34	68.69	0.08	0.21	0.64	0.94	1.00	1.00
Coniferous habitat	68.00	4.17	86.52	0.10	0.27	0.80	0.97	1.00	1.00
Mixed habitat	70.00	4.31	75.37	0.08	0.21	0.63	0.93	1.00	1.00
Yellow-bellied Sapsucker	38.67	1.35	84.58	0.26	0.80	1.00	1.00	1.00	1.00
Least Flycatcher	21.67	0.94	206.54	0.09	0.23	0.68	0.96	1.00	1.00
Blue Jay	60.00	0.62	169.20	0.27	0.80	1.00	1.00	1.00	1.00
Red-winged Blackbird	14.67	1.05	186.10	0.07	0.15	0.47	0.81	0.97	1.00
White-throated Sparrow	51.00	1.80	136.96	0.13	0.38	0.91	1.00	1.00	1.00
Nashville Warbler	65.00	1.40	346.08	0.10	0.28	0.80	0.99	1.00	1.00
Yellow-rumped Warbler	59.33	1.50	117.71	0.16	0.48	0.97	1.00	1.00	1.00
Black-throated Green Warbler	46.00	0.85	296.32	0.16	0.50	0.98	1.00	1.00	1.00
Ovenbird	49.67	0.79	162.95	0.26	0.80	1.00	1.00	1.00	1.00
Winter Wren	48.33	0.86	113.05	0.48	0.97	1.00	1.00	1.00	1.00
Black-capped Chickadee	58.00	1.95	80.54	0.22	0.65	1.00	1.00	1.00	1.00
Golden-crowned Kinglet	45.33	1.98	115.62	0.13	0.39	0.92	1.00	1.00	1.00
Hermit Thrush	53.67	1.18	104.36	0.27	0.80	1.00	1.00	1.00	1.00
American Robin	56.67	1.04	107.61	0.31	0.83	1.00	1.00	1.00	1.00

Table 2. Mean (control and treatment 1988, 1989, 1990), coefficient of variation sample size (mean of segments where individual occurred over 3 years), and power of t-test (two-tailed) based on the difference between post- and pre-operational antenna bird parameters for June. Transects with zero counts during pre and post years are not included. Logged sites were also excluded. For example, the power of detecting a difference in post- and pre-operational numbers of one Hermit Thrush individual between control and treatment study areas is 0.86 (if such a difference exists).

Parameter	N	Mean	CV	Change in number of individuals (post-pre)					
				0.5	1	2	3	4	5
Total individuals	70.00	23.75	34.57	0.05	0.08	0.21	0.41	0.63	0.82
Total no. species	70.00	11.77	30.79	0.10	0.26	0.80	0.98	1.00	1.00
Permanent resident	67.67	2.06	90.36	0.15	0.46	0.96	1.00	1.00	1.00
Short distance migrant	69.67	6.14	80.21	0.09	0.25	0.80	0.97	1.00	1.00
Long distance migrant	70.00	15.16	43.77	0.05	0.11	0.30	0.58	0.82	0.95
Ground nests	70.00	9.97	45.74	0.07	0.18	0.54	0.87	0.99	1.00
Canopy nests	70.00	6.89	57.07	0.09	0.23	0.69	0.96	1.00	1.00
Subcanopy nests	68.33	4.44	103.88	0.08	0.20	0.61	0.92	0.99	1.00
Ground ins. & seeds	57.67	2.32	109.48	0.17	0.53	0.98	1.00	1.00	1.00
Foliage insects	70.00	11.05	42.87	0.07	0.15	0.44	0.80	0.95	0.99
Ground invertebrates	70.00	5.37	58.33	0.12	0.33	0.87	1.00	1.00	1.00
Deciduous habitat	70.00	9.61	66.27	0.07	0.15	0.46	0.80	0.96	1.00
Coniferous habitat	57.33	2.67	94.19	0.16	0.50	0.97	1.00	1.00	1.00
Mixed habitat	70.00	5.81	57.06	0.11	0.32	0.85	0.99	1.00	1.00
Yellow-bellied Flycatcher	27.33	0.85	103.20	0.26	0.80	1.00	1.00	1.00	1.00
Least Flycatcher	21.67	2.76	142.53	0.06	0.12	0.34	0.64	0.87	0.97
White-throated Sparrow	43.33	1.61	112.84	0.18	0.54	0.98	1.00	1.00	1.00
Rose-breasted Grosbeak	48.67	1.18	104.76	0.23	0.69	1.00	1.00	1.00	1.00
Red-eyed Vireo	62.00	1.94	105.82	0.20	0.61	1.00	1.00	1.00	1.00
Black-and-white Warbler	42.67	0.78	119.04	0.27	0.80	1.00	1.00	1.00	1.00
Nashville Warbler	57.67	2.68	81.36	0.14	0.43	0.95	1.00	1.00	1.00
Chestnut-sided Warbler	44.67	1.54	118.35	0.11	0.30	0.82	1.00	1.00	1.00
Black-throated Green Warbler	50.00	1.74	98.86	0.19	0.57	1.00	1.00	1.00	1.00
Ovenbird	70.00	3.36	72.17	0.21	0.62	1.00	1.00	1.00	1.00
Mourning Warbler	43.67	0.43	177.17	0.17	0.51	0.98	1.00	1.00	1.00
Black-capped Chickadee	35.33	1.12	111.22	0.17	0.53	0.98	1.00	1.00	1.00
Golden-crowned Kinglet	36.67	1.49	101.27	0.21	0.63	1.00	1.00	1.00	1.00
Hermit Thrush	53.67	1.14	94.64	0.33	0.86	1.00	1.00	1.00	1.00
American Robin	47.67	0.53	165.89	0.44	0.95	1.00	1.00	1.00	1.00

Table 3. Mean (control and treatment 1988, 1989, 1990), coefficient of variation, sample size (mean of segments where individual occurred over 3 years), and power of t-test based on the difference between post- and pre-operational antenna bird parameters for July. Transects with zero counts during pre and post years are not included. Logged sites were also excluded. For example, the power of detecting a difference in post- and pre-operational numbers of two Black-capped Chickadee individuals between control and treatment study areas is 0.88 (if such a difference exists).

Parameter	N	Mean	CV	Change in number of individuals (post-pre)					
				0.5	1	2	3	4	5
Total individuals	70.00	21.93	39.83	0.04	0.07	0.15	0.28	0.44	0.62
Total no. species	70.00	10.23	33.32	0.10	0.29	0.80	0.99	1.00	1.00
Permanent resident	69.00	3.03	106.72	0.08	0.21	0.63	0.93	1.00	1.00
Short distance migrant	69.67	7.55	66.73	0.06	0.12	0.35	0.66	0.89	0.98
Long distance migrant	70.00	10.80	57.48	0.06	0.14	0.41	0.80	0.94	1.00
Ground nests	70.00	8.94	58.63	0.09	0.13	0.40	0.72	0.93	1.00
Canopy nests	70.00	6.24	65.15	0.05	0.15	0.45	0.80	0.96	1.00
Subcanopy nests	65.00	3.41	109.30	0.12	0.35	0.89	0.95	1.00	1.00
Ground ins. & seeds	55.00	2.50	98.26	0.09	0.22	0.66	0.94	1.00	1.00
Foliage insects	70.00	9.25	57.44	0.05	0.11	0.29	0.57	0.81	0.94
Ground invertebrates	70.00	5.41	63.52	0.09	0.23	0.68	0.95	1.00	1.00
Deciduous habitat	70.00	8.37	72.00	0.06	0.13	0.38	0.70	0.91	0.99
Coniferous habitat	59.67	2.63	123.58	0.09	0.25	0.73	0.97	1.00	1.00
Mixed habitat	70.00	5.34	71.25	0.09	0.24	0.70	0.96	1.00	1.00
Least Flycatcher	22.33	1.66	184.60	0.08	0.21	0.64	0.94	1.00	1.00
White-throated Sparrow	45.67	1.58	117.48	0.12	0.36	0.89	1.00	1.00	1.00
Red-eyed Vireo	61.67	1.88	113.27	0.16	0.49	0.97	1.00	1.00	1.00
Nashville Warbler	54.33	2.04	140.42	0.10	0.27	0.80	0.98	1.00	1.00
Chestnut-sided Warbler	34.00	1.26	116.15	0.19	0.58	0.99	1.00	1.00	1.00
Black-throated Green Warbler	42.67	1.55	102.81	0.18	0.54	0.99	1.00	1.00	1.00
Ovenbird	66.67	2.52	80.89	0.19	0.59	0.99	1.00	1.00	1.00
Black-capped Chickadee	60.00	1.25	149.62	0.12	0.35	0.88	1.00	1.00	1.00
Golden-crowned Kinglet	37.00	1.73	141.77	0.09	0.23	0.70	0.96	1.00	1.00
Hermit Thrush	67.33	1.78	94.27	0.19	0.59	0.99	1.00	1.00	1.00

Table 4. Mean (control and treatment 1988, 1989, 1990), coefficient of variation, sample size (mean of segments where individual occurred over 3 years), and power of t-test (two-tailed) based on the difference between post- and pre-operational antenna bird parameters for August. Transects with zero counts during pre and post years are not included. Logged sites were also excluded. For example, the power of detecting a difference in post- and pre-operational numbers of one Hermit Thrush individual between control and treatment study areas is 0.85 (if such a difference occurred).

Parameter	N	Mean	CV	Change in number of individuals (post-pre)					
				0.5	1	2	3	4	5
Total individuals	70.00	12.12	71.83	0.05	0.09	0.25	0.48	0.73	0.89
Total no. species	70.00	5.58	55.01	0.12	0.35	0.88	1.00	1.00	1.00
Permanent resident	69.67	4.46	102.71	0.09	0.25	0.73	0.97	1.00	1.00
Short distance migrant	69.00	4.20	110.84	0.07	0.16	0.47	0.81	0.97	1.00
Long distance migrant	65.00	2.52	99.24	0.15	0.45	0.95	1.00	1.00	1.00
Ground nests	63.67	2.42	107.68	0.12	0.35	0.88	1.00	1.00	1.00
Canopy nests	67.67	4.14	90.75	0.09	0.25	0.73	0.97	1.00	1.00
Subcanopy nests	44.00	1.16	156.89	0.20	0.61	1.00	1.00	1.00	1.00
Ground ins. & seeds	40.67	1.26	186.13	0.11	0.33	0.86	1.00	1.00	1.00
Foliage insects	69.00	4.82	93.07	0.08	0.21	0.63	0.93	1.00	1.00
Ground invertebrates	63.33	1.68	98.67	0.19	0.59	1.00	1.00	1.00	1.00
Deciduous habitat	70.00	4.47	97.01	0.08	0.21	0.63	0.93	1.00	1.00
Coniferous habitat	56.67	2.77	127.31	0.10	0.26	0.80	0.98	1.00	1.00
Mixed habitat	63.33	1.98	97.11	0.21	0.59	1.00	1.00	1.00	1.00
Red-eyed Vireo	38.67	1.13	120.49	0.26	0.80	1.00	1.00	1.00	1.00
Red-breasted Nuthatch	45.00	1.33	131.40	0.20	0.62	1.00	1.00	1.00	1.00
Black-capped Chickadee	63.00	2.18	115.10	0.14	0.41	0.93	1.00	1.00	1.00
Golden-crowned Kinglet	40.67	1.79	148.17	0.09	0.23	0.68	0.96	1.00	1.00
Hermit Thrush	39.67	1.14	92.56	0.32	0.85	1.00	1.00	1.00	1.00

Table 5. Mean (control and treatment 1988, 1989, 1990), coefficient of variation, sample size (mean of segments where individual occurred over 3 years), and power of t-test (two-tailed) based on the difference between post- and pre-operational antenna bird parameters for September. Transects with zero counts during pre and post years are not included. Logged sites were also excluded. For example, the power of detecting a difference in post- and pre-operational numbers of one Red-breasted Nuthatch individual between control and treatment study areas is 0.88 (if such a difference occurred).

Parameter	N	Mean	CV	Change in number of individuals (post-pre)					
				0.5	1	2	3	4	5
Total individuals	70.00	11.61	69.89	0.04	0.06	0.14	0.25	0.40	0.57
Total no. species	70.00	5.02	54.96	0.10	0.29	0.80	1.00	1.00	1.00
Permanent resident	69.33	5.30	89.80	0.07	0.15	0.46	0.80	0.96	1.00
Short distance migrant	68.67	3.01	106.44	0.07	0.15	0.46	0.80	0.96	1.00
Long distance migrant	61.67	2.12	126.83	0.08	0.20	0.62	0.92	1.00	1.00
Ground nests	65.67	1.71	112.02	0.13	0.39	0.92	1.00	1.00	1.00
Canopy nests	69.67	3.69	110.78	0.07	0.15	0.45	0.80	0.95	1.00
Subcanopy nests	32.33	0.80	169.52	0.20	0.61	1.00	1.00	1.00	1.00
Ground ins. & seeds	26.67	0.83	170.35	0.11	0.32	0.84	1.00	1.00	1.00
Foliage insects	67.67	4.90	96.03	0.05	0.09	0.23	0.45	0.68	0.86
Ground invertebrates	65.00	1.33	115.45	0.22	0.66	1.00	1.00	1.00	1.00
Deciduous habitat	70.00	5.07	83.23	0.06	0.13	0.37	0.69	0.90	0.99
Coniferous habitat	60.67	2.64	133.45	0.08	0.20	0.61	0.92	1.00	1.00
Mixed habitat	57.67	1.31	132.83	0.22	0.61	1.00	1.00	1.00	1.00
Blue Jay	57.00	1.08	126.44	0.22	0.67	1.00	1.00	1.00	1.00
White-throated Sparrow	25.33	0.64	184.52	0.11	0.31	0.84	1.00	1.00	1.00
Red-eyed Vireo	19.67	1.16	150.27	0.13	0.39	0.92	1.00	1.00	1.00
Red-breasted Nuthatch	51.67	1.34	123.58	0.34	0.88	1.00	1.00	1.00	1.00
Black-capped Chickadee	60.00	2.71	101.30	0.07	0.16	0.50	0.84	0.97	1.00
Golden-crowned Kinglet	44.67	1.54	170.38	0.07	0.17	0.52	0.86	0.98	1.00

The coefficient of variation better reflects the sensitivity of our tests in detecting a percentage difference between control and treatment mean differences. Coefficients of variation were lowest for community parameters (number of individuals and species) and highest for individual species (Tables 1 to 5). Overall, coefficients of variation for most parameters were lowest in May, June, and July and higher during the fall migration period (August and September).

Power of statistical tests presented here differ from previous reports primarily because we are using a different statistical model to test for EM exposure effects. The power of the before-and-after test is generally lower than the power calculated with a standard t-test or two-way ANOVA with means. For example, with previous calculations we determined that we could detect a difference of one species between control and treatment areas (if such a difference occurred). With the before-and-after model, we can detect a change of two species between control and treatment study areas. For example, if ΔT (post-pre species) was 3.1 and ΔC was 1.1 we would have a > 84% chance of detecting this change in each season (Tables 1 to 5). Fewer differences between control and treatment study areas were observed when we used the before-and-after statistical model. However, many of the differences detected with the standard t-test or two-way ANOVA were present before the antenna was operational (probably due to inherent differences in habitat between control and treatment areas). We prefer the before-and-after test because it compares each study area to itself; controlling for habitat differences. In addition, this model directly tests our null hypothesis (see page 2).

Findings to date

We have not found any convincing evidence that ELF electromagnetic fields produced by the antenna in Michigan has affected breeding or migrating birds. Summary of major findings to date indicated that about 13% (4 of 30) of the community parameters tested showed a significant difference between control and treatment in before-and-after tests (Table 6). Half (2 of 4) of the significant tests showed that numbers of species or individuals in treatment areas decreased less overall in post versus pre-operational years compared to control study areas over the same time period. Summary of significant findings for all guild analyses indicated that 8.5% of all tests (23 of 270) were significantly different between control and treatment study areas. However, 78% (18 of 23) indicated that control study areas showed a greater decrease in bird numbers between pre and post operational years than the treatment study areas. Only about 7% of individual species tests (10 of 150) were significantly different with the before-and-after test. Of these, 60% (6 of 10) indicated that the individual species decreased less in treatment compared to control areas during post operational years. Overall, few parameters showed consistent differences among months or years (Table 6).

Table 6. Summary of major findings by parameter for pre- and post-operational comparisons of change in control (ΔC) and change in treatment (ΔT) study areas.

Parameter	Result ¹	Month	Year
Total individuals	$\Delta T < \Delta C$	May	1989
	$\Delta T > \Delta C$	August	1989
Total species	$\Delta T < \Delta C$	May	1989
	$\Delta T > \Delta C$	August	1989
Ground nesters	$\Delta T > \Delta C$	June	1989
Subcanopy nesters	$\Delta T < \Delta C$	May	1988, 1989
	$\Delta T < \Delta C$	June	1988, 1990
Cavity nesters	$\Delta T < \Delta C$	July	1989, 1990
	$\Delta T < \Delta C$	August	1990
Permanent residents	$\Delta T < \Delta C$	July	1990
Short-distance migrants	$\Delta T < \Delta C$	August	1989
Long-distance migrants	$\Delta T < \Delta C$	May	1989, 1990
Coniferous habitat	$\Delta T < \Delta C$	August	1989
	$\Delta T > \Delta C$	September	1988
Mixed upland habitat	$\Delta T > \Delta C$	June	1989
Lowland conifer habitat	$\Delta T < \Delta C$	May	1989
Ground insects & seeds	$\Delta T < \Delta C$	June	1988
Ground invertebrates	$\Delta T < \Delta C$	May	1989, 1990
Flycatchers	$\Delta T > \Delta C$	July	1989
Bark insects	$\Delta T > \Delta C$	July	1988
	$\Delta T < \Delta C$	July	1990
	$\Delta T < \Delta C$	August	1990
Nashville Warbler	$\Delta T > \Delta C$	May	1988, 1989
Ovenbird	$\Delta T < \Delta C$	May	1990
Hermit Thrush	$\Delta T < \Delta C$	May	1990
Least Flycatcher	$\Delta T < \Delta C$	June	1989, 1990
Mourning Warbler	$\Delta T > \Delta C$	June	1989, 1990
Red-eyed Vireo	$\Delta T < \Delta C$	July	1988
Blue Jay	$\Delta T < \Delta C$	September	1989

¹ $\Delta T < \Delta C$ = change in treatment less than change in control
 $\Delta T > \Delta C$ = change in treatment greater than change in control

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Appendix 3. Total number of individuals and species observed on control(C) and treatment(T) transects in Michigan during five census periods in 1991. English and scientific names follow AOU (1983).

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Appendix 3. Total number of individuals and species observed on control(C) and treatment(T) transects in Michigan during five census periods in 1991. English and scientific names follow AOU (1983).

	May		June		July		August		September	
	T	C	T	C	T	C	T	C	T	C
Pied-billed Grebe <u>Podilymbus podiceps</u>	0	0	0	0	0	1	0	0	0	0
American Bittern <u>Botaurus lentiginosus</u>	1	1	0	0	0	0	0	0	0	1
Canada Goose <u>Branta canadensis</u>	0	2	0	0	0	0	0	0	0	0
Wood Duck <u>Aix sponsa</u>	0	0	0	3	0	0	0	3	0	0
Mallard <u>Anas platyrhynchos</u>	1	4	0	0	0	0	0	0	0	0
Blue-winged Teal <u>Anas discors</u>	0	2	0	0	0	0	0	0	0	0
Sharp-shinned Hawk <u>Accipiter striatus</u>	0	1	0	1	0	1	0	2	0	0
Northern Goshawk <u>Accipiter gentilis</u>	0	0	1	0	0	0	0	0	0	0
Broad-winged Hawk <u>Buteo platypterus</u>	0	2	2	0	0	2	5	0	0	0
Red-tailed Hawk <u>Buteo jamaicensis</u>	0	0	0	0	0	0	1	1	0	0
American Kestrel <u>Falco sparverius</u>	1	2	2	2	5	1	6	0	1	0
Merlin <u>Falco columbarius</u>	0	0	0	0	0	0	0	1	0	0
Ruffed Grouse <u>Bonasa umbellus</u>	17	10	3	0	3	15	1	5	10	7
Virginia Rail <u>Rallus limicola</u>	0	1	0	0	0	0	0	0	0	0
Sandhill Crane <u>Grus canadensis</u>	0	1	0	2	0	0	0	0	0	0
Killdeer <u>Charadrius vociferus</u>	0	0	0	1	0	0	0	0	0	0
Greater Yellowlegs <u>Tringa melanoleuca</u>	0	1	0	0	0	0	0	0	0	0
Spotted Sandpiper <u>Actitis macularia</u>	0	0	0	0	0	1	0	1	0	0

Appendix 3 (continued)

	May		June		July		August		September	
	T	C	T	C	T	C	T	C	T	C
Common Snipe <u>Gallinago gallinago</u>	1	0	0	0	0	0	0	0	0	0
American Woodcock <u>Scolopax minor</u>	1	0	1	3	2	4	0	2	2	1
Mourning Dove <u>Zenaida macroura</u>	1	0	0	0	0	1	0	0	0	0
Black-billed Cuckoo <u>Coccyzus erythrophthalmus</u>	0	0	2	0	0	0	0	0	0	1
Yellow-billed Cuckoo <u>Coccyzus americanus</u>	0	0	0	0	0	0	0	0	0	1
Ruby-throated Hummingbird <u>Archilochus colubris</u>	0	0	1	3	0	1	0	0	0	0
Belted Kingfisher <u>Ceryle alcyon</u>	0	0	0	0	0	1	1	1	0	0
Yellow-bellied Sapsucker <u>Sphyrapicus varius</u>	19	42	4	17	10	24	1	7	0	1
Downy Woodpecker <u>Picoides pubescens</u>	3	7	1	1	0	10	7	0	14	11
Hairy Woodpecker <u>Picoides villosus</u>	2	5	7	3	3	5	6	3	6	2
Black-backed Woodpecker <u>Picoides arcticus</u>	1	0	0	0	1	0	0	0	0	1
Northern Flicker <u>Colaptes auratus</u>	17	14	6	2	11	5	10	8	31	15
Pileated Woodpecker <u>Dryocopus pileatus</u>	0	2	1	1	0	2	2	2	1	12
Olive-sided Flycatcher <u>Contopus borealis</u>	0	1	0	1	0	0	1	0	0	0
Eastern Wood-Pewee <u>Contopus virens</u>	0	1	6	12	10	9	7	15	3	3
Yellow-bellied Flycatcher <u>Empidonax flaviventris</u>	0	0	21	9	4	9	2	2	0	0
Alder Flycatcher <u>Empidonax alnorum</u>	0	0	12	5	4	0	5	1	0	0
Least Flycatcher <u>Empidonax minimus</u>	2	37	12	41	6	39	0	4	1	0
Eastern Phoebe <u>Sayornis phoebe</u>	1	1	0	1	0	0	0	0	0	0

Appendix 3 (continued)

	May		June		July		August		September	
	T	C	T	C	T	C	T	C	T	C
Great Crested Flycatcher <u>Myiarchus crinitus</u>	1	5	9	14	6	9	1	5	0	3
Eastern Kingbird <u>Tyrannus tyrannus</u>	0	0	3	0	1	3	1	3	0	0
Tree Swallow <u>Tachycineta bicolor</u>	0	5	0	0	0	0	0	0	0	0
Gray Jay <u>Perisoreus canadensis</u>	2	0	0	6	2	0	0	2	6	9
Blue Jay <u>Cyanocitta cristata</u>	24	18	15	15	19	15	35	14	35	26
American Crow <u>Corvus brachyrhynchos</u>	1	0	0	0	2	0	0	1	0	0
Common Raven <u>Corvus corax</u>	1	4	0	1	2	2	2	0	2	0
Black-capped Chickadee <u>Parus atricapillus</u>	50	39	21	20	42	86	73	83	66	70
Boreal Chickadee <u>Parus hudsonicus</u>	6	4	3	0	1	1	2	0	2	0
Red-breasted Nuthatch <u>Sitta canadensis</u>	3	5	3	2	10	12	11	18	82	50
White-breasted Nuthatch <u>Sitta carolinensis</u>	2	3	1	1	3	7	2	16	0	0
Brown Creeper <u>Certhia americana</u>	9	27	8	15	1	6	3	15	13	10
House Wren <u>Troglodytes aedon</u>	1	0	0	0	1	4	1	0	0	0
Winter Wren <u>Troglodytes troglodytes</u>	17	37	15	24	16	38	4	10	0	6
Sedge Wren <u>Cistothorus platensis</u>	0	2	1	8	1	5	0	7	0	1
Golden-crowned Kinglet <u>Regulus satrapa</u>	46	36	48	31	49	40	7	12	15	11
Ruby-crowned Kinglet <u>Regulus calendula</u>	19	9	4	2	1	0	0	0	1	0
Eastern Bluebird <u>Sialia sialis</u>	0	0	3	2	0	0	0	0	3	0
Veery <u>Catharus fuscescens</u>	2	0	9	12	12	19	1	0	0	2

Appendix 3 (continued)

	May		June		July		August		September	
	T	C	T	C	T	C	T	C	T	C
Swainson's Thrush <u>Catharus ustulatus</u>	0	0	0	0	0	0	0	0	0	3
Hermit thrush <u>Catharus guttatus</u>	18	27	35	39	76	64	31	46	8	14
Wood Thrush <u>Hylocichla mustelina</u>	0	6	0	1	0	8	0	0	0	1
American Robin <u>Turdus migratorius</u>	29	21	24	15	19	23	16	12	7	8
Brown Thrasher <u>Toxostoma rufum</u>	8	0	7	0	2	1	0	0	0	0
Cedar Waxwing <u>Bombycilla cedrorum</u>	0	0	19	14	15	10	81	28	16	28
Solitary Vireo <u>Vireo solitarius</u>	5	9	5	6	3	9	0	1	4	2
Yellow-throated Vireo <u>Vireo flavifrons</u>	0	0	2	3	0	0	0	0	0	0
Red-eyed Vireo <u>Vireo olivaceus</u>	1	0	68	66	83	93	37	39	23	34
Golden-winged Warbler <u>Vermivora chrysoptera</u>	2	2	6	2	0	0	0	0	0	0
Tennessee Warbler <u>Vermivora peregrina</u>	0	0	0	0	0	0	0	0	1	0
Nashville Warbler <u>Vermivora ruficapilla</u>	44	47	114	64	95	64	2	1	4	4
Northern Parula <u>Parula americana</u>	1	11	1	9	2	5	0	2	3	1
Yellow Warbler <u>Dendroica petechia</u>	0	0	0	5	0	0	0	0	1	0
Chestnut-sided Warbler <u>Dendroica pensylvanica</u>	4	4	52	17	25	12	2	0	0	0
Magnolia Warbler <u>Dendroica magnolia</u>	0	0	2	0	6	1	0	0	0	0
Yellow-rumped Warbler <u>Dendroica coronata</u>	47	40	19	19	9	14	6	1	10	0
Black-throated Green Warb. <u>Dendroica virens</u>	14	57	37	50	44	58	1	5	0	0
Blackburnian Warbler <u>Dendroica fusca</u>	0	8	4	5	0	7	0	0	0	0

Appendix 3 (continued)

	May		June		July		August		September	
	T	C	T	C	T	C	T	C	T	C
Pine Warbler <u>Dendroica pinus</u>	1	0	0	0	1	1	0	0	0	0
Palm Warbler <u>Dendroica palmarum</u>	2	2	1	0	2	2	0	0	0	0
Black-and-white Warbler <u>Mniotilta varia</u>	8	16	13	19	6	10	5	0	0	4
American Redstart <u>Setophaga ruticilla</u>	0	0	0	0	0	0	1	0	0	3
Ovenbird <u>Seiurus aurocapillus</u>	37	60	107	127	93	131	11	11	12	10
Northern Waterthrush <u>Seiurus noveboracensis</u>	4	3	0	0	0	0	0	0	0	0
Mourning Warbler <u>Oporornis philadelphia</u>	0	0	21	17	2	16	5	0	0	0
Common Yellowthroat <u>Geothlypis trichas</u>	0	0	15	24	17	25	3	16	9	2
Canada Warbler <u>Wilsonia canadensis</u>	0	0	1	5	0	1	0	0	0	0
Scarlet Tanager <u>Piranga olivacea</u>	1	6	5	9	10	15	0	2	1	1
Rose-breasted Grosbeak <u>Pheucticus ludovicianus</u>	10	17	12	22	3	32	2	1	2	0
Indigo Bunting <u>Passerina cyanea</u>	0	0	12	13	20	30	3	2	0	0
Rufous-sided Towhee <u>Pipilo erythrophthalmus</u>	4	5	6	3	6	2	1	1	2	0
Chipping Sparrow <u>Spizella passerina</u>	5	18	6	6	3	11	0	7	0	10
Vesper Sparrow <u>Poocetes gramineus</u>	0	0	0	0	1	0	1	0	0	0
Song Sparrow <u>Melospiza melodia</u>	0	9	13	12	4	13	0	1	2	0
Lincoln's Sparrow <u>Melospiza lincolni</u>	0	0	1	0	0	0	1	0	0	0
Swamp Sparrow <u>Melospiza georgiana</u>	9	10	6	23	8	10	3	3	0	0
White-throated Sparrow <u>Zonotrichia albicollis</u>	54	23	39	20	46	23	13	14	19	15

Appendix 3 (continued)

	May		June		July		August		September	
	T	C	T	C	T	C	T	C	T	C
Dark-eyed Junco <u>Junco hyemalis</u>	2	0	0	0	2	0	0	0	0	0
Red-winged blackbird <u>Agelaius phoeniceus</u>	0	10	0	5	3	2	0	0	0	0
Brewer's Blackbird <u>Euphagus cyanocephalus</u>	0	0	0	2	0	0	0	0	0	0
Common Grackle <u>Quiscalus quiscula</u>	4	5	0	3	23	5	0	1	0	0
Brown-headed Cowbird <u>Molothrus ater</u>	1	4	2	5	0	4	0	0	0	0
Northern Oriole <u>Icterus galbula</u>	0	1	2	2	0	0	0	0	0	0
Purple Finch <u>Carpodacus purpureus</u>	2	10	2	1	2	3	0	0	2	0
Pine Siskin <u>Carduelis pinus</u>	0	0	0	0	0	0	0	1	0	0
American Goldfinch <u>Carduelis tristis</u>	0	2	4	3	1	0	9	5	4	9
Evening Grosbeak <u>Coccothraustes vespertinus</u>	0	2	0	0	1	0	0	1	1	0
Unidentified passerine Unidentified passerine	8	10	5	10	27	18	123	103	176	96
Unidentified sparrow Unidentified sparrow	0	0	0	0	0	0	0	0	0	1
Unidentified thrush Unidentified thrush	0	0	0	0	0	0	0	0	1	2
Unidentified woodpecker Unidentified woodpecker	1	2	2	0	4	3	3	8	4	9
Unidentified warbler Unidentified warbler	0	0	0	0	0	0	0	0	6	9
Total individuals	578	778	895	907	892	1104	558	556	612	510
Total species	55	60	63	66	59	65	47	50	37	38

Appendix 4. Presentations, publications, and manuscripts based on work conducted as part of the ELF monitoring program.

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Presentations

Hanowski, J.M., and G.J. Niemi. 1987. Statistical perspectives and experimental design in bird censusing. American Ornithologists Union; San Francisco State University; August 1987.

Hanowski, J.M., and G.J. Niemi. 1987. Assessing the effects of an extremely low frequency (ELF) antenna system on bird species and communities in northern Wisconsin and Michigan. Lake Superior Biological Conference; University of Minnesota-Duluth; September 1987.

Blake, J.G., J.M. Hanowski, G.J. Niemi, and P.T. Collins. 1988. Seasonal and annual variation in the influence of time of day on bird censuses. Cooper Ornithological Society, Asilomar, California; March 1988.

Blake, J.G., G.J. Niemi, and J.M. Hanowski. 1989. Annual variation in bird populations: some consequences of scale of analysis. Cooper Ornithological Society, Moscow, Idaho; June 1989.

Blake, J.G., G.J. Niemi, and J.M. Hanowski. 1989. Drought and annual variation in bird populations: effects of migratory strategy and breeding habitat. Symposium on Ecology and Conservation of Neotropical Migrant Landbirds, Woods Hole, Massachusetts; December 1989.

Hanowski, J. M., J. G. Blake, and G. J. Niemi. 1990. Seasonal bird distribution patterns along habitat edges in northern Wisconsin. Lake Superior Biological Conference, Ashland, Wisconsin; September 1990.

Hanowski, J. M., G. J. Niemi, J. G. Blake, and P. T. Collins. 1990. Effects of extremely low frequency electromagnetic fields on bird species and communities.

- Annual Review of Research on Biological Effects of 50/60 Hz Electric and Magnetic Fields, Denver, Colorado; November 1990.
- 52nd Midwest Fish and Wildlife Conference, Minneapolis, Minnesota; December 1990.
- XX Congressus Internationalis Ornithologicus, Christchurch, New Zealand; December 1990.

Collins, P.T. 1990. Birds and invertebrates in northern Wisconsin forests: Are they related?

- University of Minnesota, Duluth; May 1991.
- American Ornithologists' Union; McGill University, Montreal; September 1991.

Publications

- Blake, J.G., G.J. Niemi, and J.M. Hanowski. Drought and annual variation in bird populations. In J. Hagan and D. W. Johnston, eds., *Ecology and conservation of neotropical landbird migrants*. Smithsonian Institution Press, Washington, DC. In press.
- Blake, J.G., J.M. Hanowski, G.J. Niemi, and P.T. Collins. 1991. Hourly variation in transect counts of birds. *Ornis Fennica* 68: in press.
- Collins, P.T. 1991. Relationships between invertebrate biomass and bird abundance in northern Wisconsin forests. MS thesis, University of Minnesota.
- Hanowski, J.M., G.J. Niemi, and J.G. Blake. 1990. Statistical perspectives and experimental design in counting birds with line transects. *Condor* 92:328-337.

Manuscripts (in review)

- Hanowski, J.M., J.G. Blake, and G.J. Niemi. Seasonal abundance and composition of bird communities adjacent to forest edges in northern Wisconsin. Submitted to *Canadian Journal of Zoology*.
- Hanowski, J. M., J. G. Blake, G. J. Niemi, and P. T. Collins. Effects of extremely low frequency electromagnetic fields on breeding and migrating birds. Submitted to *American Midland Naturalist*.
- Collins, P.T. Length-biomass relationships for terrestrial gastropods and Oligochaetes. Submitted to *American Midland Naturalist*.

Manuscripts (in preparation)

- Blake, J.G., et al. Annual variation in bird populations of mixed conifer-northern hardwoods forests.
- Collins, P.T., G.J. Niemi, J.G. Blake, and J.M. Hanowski. Lateral distance distribution patterns for northern forest birds.

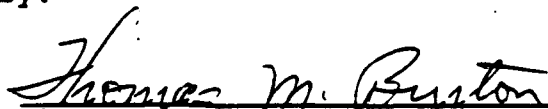
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IV. GLOSSARY AND ACRONYMS

AFDW-biomass - ash-free dry weight of organic matter that accumulates on rock or other substrate surfaces on the stream bottom. This organic matter is produced by algae, bacteria, and fungi and/or by the flocculation and settling of suspended organic matter from the water column.

Alkalinity - a chemical measure of the amount of anions in the water determined by titration with dilute acid; a rough measure of the acid neutralizing capacity of the water derived primarily from the carbonate and bicarbonate ions in it.

ANCOVA - analysis of covariance; a statistical analysis in which treatment means are compared by standardizing for differences in a common covariant (a parameter that varies with parameter in question).

ANOVA - analysis of variance; a statistical procedure for comparing whether treatment means are essentially the same or not; it is essentially an arithmetic process for partitioning a total sum of squares into components associated with recognized sources of variation.

BACI - Before and After, Control and Impact analysis-statistical analysis which compares differences between control and impact sites, both before and after antenna operation by comparing differences in the variance for each site before and after the operation of the antenna (see Stewart-Oaten et al 1986 for details - reference section of element 2).

Backcalculated length - length of fish at previous age estimated from body-scale relationship between distance between annuli on scales or otoliths and fish length at capture.

Benthos (Benthic) - organisms that live on or in the river bottom in or on substrates such as sand, gravel, and organic detritus.

Biomass - the weight of a fish stock, or of some defined portion of it.

Body-scale relationship - method of backcalculation where length is determined from the distance between annuli.

Biovolume - a crude estimate of biomass of algal cells where volume is calculated from the shape and size of individual cells using geometric formulae. Individual cell volumes are then multiplied by algal species counts and summed to get total biovolume.

Catch rates - the catch of fish, in numbers or in weight per defined unit of fishing effort.

C.C. - correlation coefficient (r); a measure of the degree to which variables vary together or a measure of the intensity of association.

C-F - collector-filter-feeding aquatic invertebrates; invertebrates that feed by collecting particles of detritus or algae from the water by use of nets or other collecting devices.

C-G - collector-gatherer aquatic invertebrates; invertebrates that feed by collecting detrital particles from substrates in the river.

Chi-square test - statistical test for goodness of fit for observed and expected frequencies.

Chlorophyll a - the primary photosynthetic pigment of most plants; in this study, it is extracted using acetone and used as a crude measure of plant productivity or standing crop.

Conductivity - a measure of the ionic strength of the water.

CPUE - the catch of fish, in numbers or in weight per defined unit of fishing effort.

C.V. - coefficient of variation; a quantity of use to the experimenter in evaluating results from different experiments involving the same character but possibly conducted by different persons.

Degree days - daily accumulation of degrees ($^{\circ}$ C) above a pre-set threshold value (in our study the threshold was 2° C).

DeLury method - removal method of population estimation. Population is estimated from the relation of fishing success

to cumulative fishing effort. Assumes fish catchability does not change throughout all sampling passes, and the population is significantly reduced with each pass. Three removals were used in this study.

Diatoms - a group of algae that often dominate unpolluted rivers (very few other kinds of algae are present in the Ford River most of the time); they are characterized by having the cells encased in two siliceous covers known as valves.

Discharge (Q) - the amount of water passing a particular point on a river over a given time period, usually expressed in cubic meters per second; it is calculated from measurements of width, depth, and velocity by taking at least 20 verticals of depth, mean velocity, and the width between the verticals across a stream or from depth measurements based on depth (stage)-discharge relationships determined empirically for the river segment being studied.

DO - Dissolved Oxygen; the amount of oxygen dissolved in water.

Electrofishing - method used in fisheries to collect/capture fish. Electric current is applied to the water which temporarily incapacitates the fish so that they can be collected.

Electrofishing efficiency - percent of the total population of fish taken by electrofishing crew.

ELF - Extremely Low Frequency electromagnetic radiation; it is derived primarily from local electric power lines or from the ELF antenna that will be used by the Navy to communicate with submarines at sea.

EPROM - Erasable Programmable Read Only Memory chip; the type of chip used to temporarily store data in the Omnidata data pods used in our ambient monitoring program; these data are transferred by use of an EPROM reader into an Apple computer and summarized.

FCD - Ford Control Downstream - site on Ford River presently used as the control site (see Fig. VII.1).

FCD-N - Ford Control Downstream New - a periphyton monitoring site located 130 m downstream of FCD.

FCU - Ford Control Upstream

FEN - Ford Experimental New - a fyke net site 400m upstream of FEX used to monitor fish movement past the antenna.

FEX - Ford Experimental - site on Ford River presently used as the primary experimental or test site; it is located where the N-S leg of the ELF antenna crosses the Ford River (see Fig. VIII.1).

FEX-Line - Ford Experimental Line - an insect studies site located 35 m downstream of FEX (about 5 m downstream of the point where the antenna crosses the river).

FEX-N - Ford Experimental New - a periphyton monitoring site located 40 m downstream of FEX (about 10 m downstream of the point where the antenna crosses the river).

FFG - Functional Feeding Groups - aquatic insects species are categorized into feeding groups according to their predominant feeding mode (See Merritt and Cummins, 1984 - reference after element 4).

FS1 - Ford Site One - one of the original study sites. Not used presently.

Freidman's test - non-parametric test comparing distributions; the null hypothesis being that the populations within a block are identical against the alternative that at least one treatment comes from populations which have a different location in one direction.

Fyke net - portable passive gear used at FCD and FEX. Nets are set in tandem, one capturing upstream migrants the other capturing downstream migrants. Nets block entire width of stream and are used in areas with unstable substrate.

Grazer - as used in this study; an invertebrate herbivore that feeds on algae on rocks and other substrates on the stream bottom.

Gross Primary Production (GPP) - the total amount of energy fixed by green plants in the process of photosynthesis in a given time period; it is equal to plant respiration plus net primary production.

Growth - incremental increase in mean length and weight. Backcalculation of lengths and body-scale relationship were used to monitor growth in this study.

H' - taxon diversity (after Shannon-Weiner). An information theory index which weights the number of taxa and the apportionment of numbers of individuals among the taxa.

Handling (Tagging) Mortality - mortality caused by weighing, measuring, tagging, etc. Calculated from recaptured fish found dead in the gear in this study. Probably underestimated.

Hardness - a rough chemical measure of the amount of cations in the water determined by titration.

Holobiotic - an organism that spends its entire life in one environmental medium; e.g., an aquatic beetle, Optioservus sp., whose larval and adult stages are aquatic.

J' - taxon evenness (after Shannon-Weiner). An index which evaluates the apportionment of numbers of individuals within each taxon.

-k/day - processing coefficient. An exponential decay model describing the rate biological material (in our case, leaves) decays per day, $\log_e (\% \text{ remaining}/100) / \text{days}$.

Kruskal-Wallis test - non-parametric statistical test comparing distributions; the null hypothesis being that the populations sampled are continuous and identical, except possibly for location.

Lee's Phenomenon - commonly seen in backcalculated length estimates. In the larger fish, backcalculated lengths at early ages are less than the true average size at that age. Usually due to differential growth or mortality. Reverse Lee's Phenomenon can occur also, especially in non-exploited populations or where predator-prey relationships do not exist or are poorly defined.

Lincoln index - an estimate of population size based on the proportion of marked organisms that are captured in a later sampling effort (see Southwood, 1978 - see references after element 2).

Mann-Whitney U test - non-parametric statistical test of two samples which gives rise to a t-test or ANOVA. Null hypothesis is that two samples come from populations having the same distribution.

Mark-recapture studies - a method for determining population size or movement of organisms based on recapture of marked individuals.

MDW/IND - mean dry weight (mg.) per individual.

N - Nitrogen when used as follows (otherwise refers to the number of samples taken):

- ammonium-N: ammonium-Nitrogen
- nitrate-N: nitrate-Nitrogen
- nitrite-N: nitrite-Nitrogen
- inorganic-N: inorganic-Nitrogen; the sum of the three N species above.
- organic-N: organic-Nitrogen; total Kjeldahl nitrogen minus ammonium nitrogen.

Naiads - the immature (nymph) stages of insects that undergo incomplete metamorphosis; e.g. dragonfly naiads.

Net Primary Production (NPP) - the amount of energy or carbon that is fixed by the process of photosynthesis that is not used in self maintenance (respiration) by the plant; it supports herbivore or detritivore food chains.

Numerical dominance - the ratio between numbers of individuals from one taxon and the total numbers of individuals found in a sample. The percentage gives the numerical dominance of that taxon.

P - predators; animals that ingest other animals.

PAR - Photosynthetically Active solar Radiation = solar radiation that most plants are able to use in photosynthesis; similar to visual range for humans.

PCA - Principal Components Analysis; a statistical procedure used to ordinate data in relation to environmental variables.

Percent recapture - the ratio between numbers of marked animals recaptured and the total number of animals marked.

Periphyton - algae, bacteria and fungi attached to the substrate, rocks, twigs or any other debris in the stream. Our studies emphasize periphytic algae attached to bottom substrates.

Phaeophytin a - the breakdown product of chlorophyll a; the ratio of chlorophyll a to phaeophytin a is sometimes used as a very crude estimate of the health of algal populations.

Predators - animals that ingest other animals.

Relative weight (Wr) - weight at length values calculated from fish being studied. Used in comparative analysis of condition against weight at length values calculated from populations in the literature.

RIA - Randomized Intervention Analysis; statistical analysis which compares mean differences between sites before and after antenna impact; a non-parametric equivalent of BACI in which the test statistic is compared to a random distribution of the data set.

S - shredder invertebrates; those that feed on large leaf fragments by shredding holes in this leaf material.

S - taxon richness. The number of taxa in a sample.

Shannon-Wiener diversity - diversity index which uses number of species and abundance within species to compute a values which is comparable between sites and years (see H' above).

Shredder - see S (first definition) above.

Standard weight (Ws) - mean weight at length values calculated from a number of populations from the literature. Wr values are measured against these values to comparatively determine the condition of fish being studied.

TB - total biomass; total weight of all organisms in the taxa being discussed.

TM - Two Mile Creek; a weir site.

T-test - statistical test of the difference between two means to analyze variance.

Turbidity - a measure of the light blocking particles suspended in the water.

Univoltine - one generation per year; used to describe aquatic insect life cycles.

VI Tag - Visible implant tag. A tag implanted in the clear tissue posterior to the eye of a fish, so that the code on the tag is visible.

Weir - semi-permanent traps used to capture fish. Made of hardware cloth held in place with rerod. Applied at beginning of study season and extracted at the end of the season. Weirs have removable weir boxes which, when in place, deter fish movement. When boxes are removed, weir is negotiable by all fish.

Yearling fish - fish that are one + years old but are not yet sexually mature.

YOY - young of year; fish hatched out earlier in the year.

V. ABSTRACT

The goal of the aquatic ecosystems project is to determine the effects of low-level, long-term, electromagnetic radiation on the biota of streams. This electromagnetic radiation will be derived from the U.S. Navy's extremely low frequency submarine communication system (ELF) located in the upper peninsula of Michigan. The specific ecosystem being studied is the Ford River, a fourth order stream that arises in northern Dickinson and southern Marquette Counties and enters the Michigan portion of Green Bay south of Escanaba, Michigan. Detailed ecological sampling and analyses are being conducted simultaneously at two primary sites. The control site (FCD) is located on a fourth order section of the Ford River in northern Dickinson County just west of the community of Ralph, Michigan. It is approximately five miles downriver from the test site (FEX) where the N-S leg of the antenna system crosses the river. These two sites were closely matched in terms of electromagnetic exposure from local electric power distribution lines prior to construction and operation of the antenna. The ELF exposure rate at FEX under full antenna power represents a five-fold increase in exposure over the exposure at FCD. In order to obtain the desired ten-fold difference in exposure rate, two new periphyton sites (FEX-N and FCD-N), one new insect study site (FEX.LINE), and one new fish movement site (FEN) were added in May, 1990. Data collected to date are either preoperational data (June, 1983 to April, 1986), transitional data (May, 1986 through September, 1989), or fully operational (Oct. 7, 1989-present). Exposure to ELF radiation was restricted to daylight hours at 4-6 amps for several days from July to October, 1986, or at 15 amps for several days from April 28 to November 15, 1987, or at 75 amps for most working days from November 15, 1987 to May 1 1989. Exposure after May 1, 1989 was at 150 amps continuously between 4 pm and 8 am on weekdays and on weekends, and intermittently between 8 am and 4 pm on weekdays. On October 7, 1989 the antenna became fully operational.

The ecological monitoring program consists of four primary components. These include: (1) an extensive program of monitoring chemical and physical environmental data for the two sites; (2) a program to determine ELF effects on the algal communities attached to the rocks on the river bottom; (3) a program to determine ELF effects on the aquatic insects; and (4) a program to determine ELF effects on the fish community with emphasis on fish movements between sites. The two primary sites (test and control, FEX and FCD) are very closely matched, both physically and chemically. Data routinely monitored at each site include stream discharge, water and air temperature, photosynthetically active solar

radiation (PAR) received above and below the water surface, pH, dissolved oxygen, alkalinity, hardness, turbidity, and nutrients used by the plants such as nitrogen, phosphorus, and silica. Paired t-tests indicate either that there are no differences between sites for most parameters or that slight differences exist that probably have no effect on the biota. Data collected on the algal community includes chlorophyll a standing crop and accrual rates, organic matter standing crop and accrual rate measured as ash free dry weight accumulation on microscope slides, diatom density, diatom individual cell volumes, diatom total biovolume, diatom community diversity and evenness, and data on percent dominance by the major diatom species. Power analyses indicated that the best parameters for detecting ELF effects included summer season data for AFDW-biomass, cell volume, species diversity and species evenness. Significant differences between FEX and FCD for AFDW-biomass, chlorophyll a accrual, cell density, species diversity and evenness were detected for before and after data sets using paired t-tests. A before and after, control and impact statistical procedure (BACI) and randomized intervention analysis (RIA) demonstrated that there was a change in the inter-site relationship between sites for the before and after data for several parameters. Biological parameters at FCD-N and FEX-N did not differ significantly from FCD and FEX, respectively. Diatom percent abundances and photosynthesis-respiration studies were not found to differ significantly between FEX and FCD using BACI analysis. Correlations with weather variables indicate that significant differences may be related to differential site responses to weather related variables such as temperature and discharge rather than to ELF effects. This indicates the importance of combining the statistical analysis of the between site relationships for biotic variables with a detailed study of the relationship of those variables with the physical environment in order to determine the potential cause of observed changes in the biotic variables.

Data collected for aquatic insect communities in substrate samples at FEX, FCD, AND FEX.LINE include structural and functional community parameters as well as growth rates for six target taxa. Leaf processing rates of fresh and of autumn-abscisced tag alder at FEX and FCD were compared, and colonization patterns of aquatic insects colonizing those leaves were analyzed using similar biotic indices as for insects in the substrates. The insects associated with the stream bottom showed distinct seasonal patterns. Coefficient of variation values were highest in the spring and fall transition periods. In the summer seasons, coefficient of variation values were at their lowest levels. Data were treated separately, season by season, using 2-Way ANOVA tests. BACI tests were performed on the nine biotic parameters for each of the three seasons (27 tests). They failed the Tukey's test for additivity five

times; once in the spring, twice in the summer, and twice in the fall season. For the 22 tests that could be run, only once were there significant differences before versus after ELF activation: taxon evenness in the summer season. ANCOVA tests and multiple linear regression analyses using the physical factors, E.L.F. cumulative ground exposure, discharge, and water temperature showed that most of the variability associated with after E.L.F. activation was attributable to discharge in the spring, to discharge and/or water temperature in the summer (including taxon evenness), and to water temperature in the fall rather than to E.L.F. cumulative ground exposure. A linear regression of discharge versus insect mass was highly significant. In fact, a second regression using only the month of May data resulted in an R^2 value of 0.79. Growth rates of the taxa analyzed were not associated with E.L.F. activation. Processing rates of fresh leaves were not significantly different between sites over the years. This was also the case for autumn-abscised leaves. The variability for six biotic parameters for insects colonizing the leaves for 24 to 28 days each year was low. Although 2-WAY ANOVA tests often showed significant site differences, those differences were similar before versus after ELF activation. Separate ANCOVA tests, using first, cumulative degree days and second, ELF cumulative exposure values showed that, often adjusted mean values differed between the sites for both covariates. Only once was there a difference between slopes for the two sites. Growth rates of four target species of insects were not shown to be affected by E.L.F. activation. However, FEX and FEX.LINE often showed significant differences in adjusted mean values and slopes. It appears that FEX.LINE is not very similar to FEX from the few data we have for those site comparisons.

The fisheries portion of the aquatic ecosystems project emphasizes the fish community structure and abundance and brook trout (Salvelinus fontinalis) growth, condition and mobility. Much of the data are obtained using 1/2 inch mesh fyke nets and 1/2 inch hardware cloth weirs. Catch statistics for all species caught by this gear are kept and used to generate data on community composition and abundance as well as data on age, length, growth, and relative condition of individual species. Seventeen species were collected at the test site (FEX) in 1991 while nineteen species were collected at the control site (FCD). Overall, the species composition and diversity were similar at the two sites with the only changes seen in the seldom caught species. Growth and condition factors were calculated for several of the more common species and compared to literature values. Length-weight regression analysis and relative weight values were used in brook trout condition analysis. Most species in the Ford River grow slower than the average calculated from populations in the literature. Brook trout

movement varied in intensity and magnitude over all years of the study due to changes in population abundance. Brook trout movements peaked in every year as temperatures exceeded their optimum for growth (16° C) and this timing was variable over all years of the study. Pre- and post-movement population estimates obtained at least 1 mile downstream of the study sites have shown that brook trout density decreases significantly after the peak movement occurs. At this time no effect of the ELF antenna operation has been detected on 1) species diversity, 2) catch by numbers or biomass, 3) mean daily brook trout movement rates, or 4) brook trout condition or length/weight regression.

Overall, we have detected no changes in the aquatic community that we can relate statistically with confidence to operation of the ELF antenna. We monitor a wide variety of population and community level parameters for the algal, insect and fish communities. Many of these have low enough coefficients of variation between the control and test sites to allow us to detect relatively subtle (20 to 30 %) differences should such differences occur.

VI. SUMMARY

This research project is directed at determining the effects of low-level, long-term, electromagnetic fields (ELF) on natural stream ecosystems and their associated plant and animal life. Detailed ecological sampling and analyses are being conducted simultaneously at two primary sites: (1) a control site, FCD, and (2) an experimental site, FEX, at the corridor of the ELF antenna. These sites have been studied since 1983 with additional sites added in 1990 for periphyton, insect, and fish movement studies. The N-S leg of the ELF antenna crosses the FEX site and was tested at 4-6 amps for several hours on several days from May to October, 1986; at 15 amps during part of several days between April 28 and November 15, 1987, at 75 amps for most working days during 1988 and at 150 amps during most working days in 1989 and has been operated at full power since October 7, 1989. The analyses reported here includes data from the three year before period, a 3.5 year transition period, and two years of full antenna operation.

Element 1- Conduct Ambient Monitoring Program

Data for all chemical and physical parameters, collected at the commencement of the study in 1983, demonstrated that the experimental and control sites were very well matched. For the majority of the parameters, there were no significant differences between sites. When significant differences did occur between the chemical constituents, they usually involved slight increases in a downstream direction. This trend of slight increase from the upstream site to the downstream site for alkalinity, hardness, nitrate, and organic nitrogen may be related to an expected accumulation of dissolved load in a downstream direction or to local land use differences between sites. Whatever the cause, the differences were small and probably would not lead to significant inter-site differences in productivity. We conducted experiments in 1987 to determine the impact of N and P inputs on the algal community. Both had to increase before significant changes in the algal community occurred. Clearly, no such shift in N and P has occurred.

Dissolved oxygen was only slightly below saturation at both sites in 1990-91 but was slightly but significantly

Chloride also was slightly but significantly higher at FEX than it was at FCD in 1990-91. This difference might reflect a slight amount of road salt influence from Highway M-95 at Channing, MI that is diluted in a downstream direction. This difference between the two sites did not occur in 1988. Even at FEX, chloride levels were only slightly higher than typical rainfall values. Thus, chloride should have little effect on the biota at either site.

Chemical and physical parameters for FEX and FCD demonstrated that these two sites were very similar in 1990-91 with significant differences between sites showing up for less than one-third of the parameters monitored. The differences that did occur were slight and should have little impact on site productivity.

Element 2 - Periphyton Studies

1. Chlorophyll a

Annual patterns for chlorophyll a standing crop and accrual were characterized by large year-to-year variability. The only consistent trend was for July-August peaks in most years and winter lows. The magnitudes of peaks also varied between years. Paired t- tests for 1990-91 data showed no significant difference between our control (FCD) and experimental sites (FEX), as well as for all data collected since 1983. "Before" (6/83-4/86) and "after" (10/89-9/91), control (FCD) and impact (FEX) (BACI) and Randomized Intervention Analysis (RIA) indicate that the between site relationship in chlorophyll a has changed since May 1989 when the antenna became fully operational. However, analysis of covariance (ANCOVA) of the after data, with ELF exposures included as a covariant, does not suggest that ELF exposures are correlated with the observed inter-site differences.

2. Organic Matter

Organic matter (AFDW-biomass) standing crop and accrual rates showed considerable year-to-year variability similar to chlorophyll a. These parameters have been consistently characterized by showing no significant differences between sites since 1983, although organic matter accrual at FEX was higher than FCD for 1990-91. The only overall trend has been for a July-August peak in standing crop and accrual rates and winter time lows for both standing crop and accrual. BACI analyses and RIA also showed that a change has occurred in AFDW-organic matter accumulation since the testing of the antenna began in 1986. The difference is attributable to summer

variability. Organic matter accrual rates were not significantly different. ANCOVA results indicate significant differences between FEX and FCD after adjustment for earth and magnetic field exposures. However, paired t-tests of the "before" and "after" data did not detect a difference between the two sites.

3. Diatom Cell Density

Diatom cell density was statistically different between sites according to paired t-tests of 1990-1991 and 1983-1991 data sets. BACI analyses and RIA also detected significant differences between the data collected before May 86 and that collected after October 1989. The increased density after operation of the antenna began may be related to low discharges and high temperatures during May and early summer in each of these years. Density was highest in May during each of these years.

4. Total Biovolume and Individual Cell Volume

Individual cell volume comparisons of diatoms between sites showed no significant differences between sites according to paired t-tests of 1990-1991 and 1983-1991 data. The 1990-1991 paired t-test for biovolume, however, indicated significant differences between sites. BACI analysis and RIA detected no significant changes in the inter-site relationship for cell volume but significant differences for biovolume as a result of summer variability. In general, average cell volume was high in winter and low in summer, whereas total biovolume tended to be highest in summer since it is the product of average volume times density.

5. Species Diversity and Evenness

Diatom species diversity and evenness at FEX and FCD were found to differ significantly in 1991 and for all data collected to date according to paired t-tests. Comparisons of the old and new sites indicated that only species diversity was significantly different between FEX-N and FCD-N during 1990-1991. Annual trends showed a high diversity and evenness during winter (except winter of 1986-87) and lower values during the summer periods. In 1991, we calculated percent abundance for all species of diatoms and presented data for those species that achieved dominance greater than 10 % for any season. Two species, Achnanthes minutissima and Cocconeis placentula were found to dominate during the 1991 summer period, with Cocconeis achieving its highest abundance ever observed since 1983. Three species achieved dominance during the winter of 1989. BACI and RIA analyses were presented for four dominant and two non-dominant species of diatoms and showed

that no significant differences have occurred before and after antenna testing began. Even so, overall diversity and evenness have changed significantly over that time period according to the paired t-tests, BACI and RIA analyses.

6. Photosynthesis-Respiration Studies

Net primary production, respiration, and gross primary production of the community on rock surfaces did not differ greatly between sites. RIA and BACI analyses indicated that there have been no significant differences between FEX and FCD sites for gross primary production rates for "before" and "after" data. This parameter may offer a precise means of detecting ELF effects on community metabolism.

Element 3 - Effects of Insect Grazer Populations of Periphyton Communities

This element was eliminated following the 1989 field season, since effects were determined to be too variable and inconsistent from year to year to be useful in detecting ELF effects. Efforts previously spent on this element were used for the periphyton studies at two additional sites for Element 2.

Element 4 - Species Richness and Biomass of Stream Insects from Artificial Substrates in Riffles

Coefficient of variation values for structural and functional community parameters were lowest during the summer season each year (June - August) and were highest during the transitional periods: Spring (April, May) and fall (September - November) seasons. In the spring, both dramatic changes in water temperature and potentials for high discharges interact with life cycle changes of the insects. In the fall, dramatic drops in water temperatures and fall rains also interact with life cycle changes of the insects. Therefore, data analyses were separated by season. The summer, more stable period, should be the season where any E.L.F. effects could be best detected. Two-Way ANOVAS showed significant year and/or site differences for many biotic parameters, with the summer season showing the fewest significant differences. Of the 27 tests (nine parameters times three seasons), only five had significant interaction terms.

Twenty-two B.A.C.I. tests showed significant before versus after differences once and that was for taxon evenness (J') in the summer. Evenness was highly

correlated with discharge at FEX in that season. Both discharge and water temperatures were significantly correlated with insect mass and with periphyton density. The relationship was highest in the spring months when discharges were at their highest. Differences in slopes, using ANCOVAs, showed that insect mass at FEX was more negatively impacted by discharge than was insect mass at FCD. There were also significant differences between site means during the summer and fall for those analyses. FEX almost always supported a higher mass of insects than FCD, accounting for the significant differences in adjusted mean values.

Multiple linear regression tests were performed with years, E.L.F. cumulative ground exposure, mean discharge, and cumulative degree days as the independent variables. In the spring, discharge accounted for more of the variation in J', S, numbers of individuals, chironomid dominance and mean insect mass than any other physical variable. In the summer, both discharge and/or cumulative degree days accounted for most of the variation in H', J', S, numbers of individuals, chironomid dominance, dominance of collector-gatherers, predator/prey ratios, and total insect mass. In the fall, cumulative degree days accounted for most of the variation of the nine biotic parameters at FEX. Multiple R^2 values were low for most of the biotic parameters at FCD in the fall. Only two significant relationships were found then; discharge versus numbers of individuals and versus chironomid dominance.

Changes in mean dry weight/individual (MDW/IND) values for three mayflies, two caddisflies, and the chironomid assemblage were presented. Thus far, one species, Paraleptophlebia mollis has been analyzed using chronological as well as physiological time (cumulative degree days) as the independent variables. There was no relationship between E.L.F. activation and changes in MDW/IND values for this species.

An additional site was added to the study in the June of 1990: FEX.LINE. This site, downstream of FEX, has higher E.L.F. fields impinging it and data from that site will be compared both with the FEX site and the reference site, FCD, in the 1992 Annual Report. We suggest that the FEX.LINE site should be deleted in 1992 because (1) it lacks pre-operational data, (2) it appears different from either of the two extant sites, and (3) efforts are increased by one-third with this site. Those energies could be used elsewhere, and reduced funding makes reasonable decisions associated with reduced effort all the more important.

Element 5 - Movement Patterns of Ophiogomphus colubrinus

This element was dropped after the 1989 field season.

Element 6 - Leaf Litter Processing

Each year, fresh leaves were processed faster than were autumn leaves at each site when all years were averaged together. There were no site differences for fresh leaves and no site differences for autumn leaves. A new site was added; namely FEX.LINE. The intensity of ELF fields are higher there than at the FEX site. Fresh and autumn leaves were placed there in 1990, and fresh leaves were placed there in 1991. Leaf processing rates were analyzed for all sites from the beginning of the study through 1990.

The lowest coefficient of variation (C.V.) values for structural and functional community parameters of the insect community on leaves occurred after the leaves had been in the river approximately four weeks. Data from that period of incubation was used in the analyses. Although 2-Way ANOVA tests often showed significant site differences, they were similar before versus after ELF activation. ANCOVA tests were run to determine whether there were relationships with (1) cumulative degree days and with (2) ELF cumulative exposures. Results were similar for the two covariates. Usually there were differences in adjusted means for the six biotic parameters for each of the covariates; only once were there significant differences between slopes.

B.A.C.V. tests could not be performed on these data, as there is only one mean value for any given year for processing rates and for any collection data. Further, the samples were non-independent, given the fact that we were looking at the continuum of processing patterns.

ANCOVAS showed that growth rates (MDW/IND values) for two species of mayflies and one species of stonefly were generally not significantly different between FEX and FCD. Comparisons between FEX and the new experimental site FEX.LINE showed that FEX.LINE was not as similar to FEX as was FCD to FEX; there were significant differences between the two experimental sites for growth rates.

Element 7 - Fish Community Composition and Abundance

1. Species Composition

Seventeen species from five orders and ten families were collected at FEX in 1991. This represents a net increase of one order, one family and three species from the previous year. Nineteen species from ten families and five orders were collected at FCD in 1991 with a net decrease of one order and one family and a net increase of one species. Overall, the species composition was similar at the two sites with the only changes seen in rare species.

2. Species Abundance

Numerically and by biomass, the catch was dominated by five species (brook trout, common shiners, creek chubs, white suckers, and burbot). Numerically, common shiners made up over 50% of the catch at both sites. The next most abundant species at FEX was white suckers followed by creek chubs, brook trout, and burbot. At FCD the next in abundance was creek chubs followed by white suckers, brook trout, and burbot. A Spearman Rank Correlation test showed that a significant correlation existed between FEX and FCD from 1985 through 1991. BACI analysis of the pre-operational vs. transitional period and the pre-operational vs. post-operational period revealed no significant differences between sites or between periods. A one-way ANOVA also detected no differences in percent catch by numbers among the three periods.

Percent catch by biomass showed different trends in community structure than catch by number at both sites. At FEX white suckers displayed the highest percentage of the catch followed by brook trout, common shiners, creek chubs, and burbot. Brook trout had the highest percentage at FCD followed by common shiners, white suckers, creek chubs, and burbot. Cyprinid biomass continued to be higher at FCD than at FEX. A Chi-square test showed that over the 9 years of the study FEX and FCD had similar catch by biomass patterns. BACI analysis and one-way ANOVA revealed a significant difference in the percent catch by biomass of burbot. There were no significant differences among pre-operational, transitional, and post-operational periods for any of the other species.

Shannon-Weaver diversity values for 1991 were similar to the lower values observed from 1988 through 1990. A Spearman Rank Correlation test indicated a similar pattern in the Shannon-Weaver index for FEX and FCD from 1983-1991. BACI analysis of pre-operational vs. transitional and pre-

operational vs. post-operational detected no difference in the index values between the periods.

3. Catch Statistics

The mean length of most species in 1991 showed no consistent year to year trends at either FEX or FCD. Overall changes in mean length have been slight, which indicates that the size structure is consistent from year to year within the mobile fish communities at FEX and FCD. The two sites continue to be similar in mean length and trends in mean length.

4. Fish Community Mobility

Most non-salmonid fish species with adequate sample sizes demonstrated site to site movement. Recapture percentages for burbot, creek chubs, and white suckers were slightly higher in 1991 than in previous years. The common shiner recapture percentage was slightly less this year.

5. Individual Species Analyses

Age, growth and condition factor analysis using common shiners, creek chubs and white suckers was initiated as a section of this element in 1986 with the premise that these factors are good indicators of fish stress. Fish condition was examined using relative condition factors. Standard weight formulas were derived for common shiners, creek chubs and white suckers from literature data. White sucker condition factor was below the species means reported in literature for all years. Common shiner condition factor declined to below the literature mean for the first time to slightly below the literature mean in 1991. Creek chub condition factor has remained below the literature mean since 1986. The method for determining age and growth has been changed from scale analysis to length frequency distribution analysis. Consequently, this analysis is in its early stages and no conclusion can be drawn as of this date.

6. Fixed Gear Calibration

This study is designed to determine a functional relationship between fixed gear catch and actual fish densities. Net and weir catches can then be used to more accurately determine fish densities in the Ford River. DeLury estimates showed that fish densities and biomass declines from upstream sites to downstream sites. Also pre-movement (Spring) populations and biomass are higher than post-movement (Summer) estimates at all sites.

Element 8 - Brook Trout Movement

1. Movement Patterns and Rates

Brook trout catches peaked in late spring-early summer at all sites. The peak occurred in June in 1984, 1987, 1988 and 1989, and in July in 1985 and 1990 with the movement in an upstream direction. Peak catches in 1984, 1985, 1987 and 1988 were not seen in 1986, 1989, or 1990. Brook trout catches in 1991 increased from late May until mid June and remained high until mid July. Brook trout movement appeared to be initiated by mean daily water temperatures exceeding the optimal growth temperature (16° C). Movement rates are probably controlled by how quickly water temperatures increase past optimal in spring. Low groundwater discharge and river flow volumes also may create thermal barriers to movement. Ground water recharge through spring snowmelt and precipitation are also important variables. Brook trout (>190 mm) move from FEX and FCD upstream toward the TM site based on a total of 1230 tagged and branded fish. In all years, TM was chosen over FCU on the basis of the mean temperature being closer to optimal growth temperature. Recapture rates were consistent from 1984 to 1985 with no movement found in 1986 and little in 1987, 1988 and 1990. Movement was observed in 1989 although not at 1984-1985 levels. Recapture rates were at their highest in 1991 with 16 fish marked at FEX and 29 fish marked at FCD being recaptured at TM. Movement rates overall all years were found to range between 0.67 to 12.7 km/day. Rates from FEX to TM were similar among 1984, 1985, 1987, 1989, and 1991 with no catches among these sites in 1986, 1988, and 1990. Brook trout movement rates from FCD to TM were greater in 1989 and 1985 than in 1984 and 1991. No movement was detected between any sites in 1986 and very little between site movement was detected in 1987 and 1990.

No differences in either mean daily movement rate or number of days between tagging and recapture were detected when the pre-operational, transitional periods, and post-operational periods were compared. The low numbers of fish detected passing under the antenna during the transitional period and 1990 could have been due to an increase in the number of beaver dams coupled with low water conditions. However, the movement of 45 brook trout from FCD and FEX to TM, the recapture of 3 fish marked at FCD and 1 fish marked at FEX at FEN, and the direct observance of two radio tagged brook trout passing under the antenna indicates that the antenna's electromagnetic field does not impede passage.

2. Population Analysis

Michigan Department of Natural Resources conducted four electrofishing surveys at two sites on the Ford River. The brook trout density at FS1 in June 1985 was 269 ± 47.5 per ha with biomass of 2.35 kg/ha. Most of these fish were YOY and yearling fish with very low densities of adult fish. Trout densities at FCD ranged from 60.7 fish/ha (biomass = 1.28 kg/ha) at pre-movement to 0 fish during the summer post-movement period. These densities are very low when compared to literature values and are probably indicative of the variable conditions of the Ford River. These data also indicate that a large percentage of the population moves out of the lower river (FCD site) in the Spring movement period.

ELF calibration studies determined the brook trout densities range from 0.0 fish/ha at FCD to 405.7 fish/ha at TM. Overall values are below Michigan averages and show the recruitment is low at the sites sampled (except TM).

3. Brook Trout Age, Growth and Condition

Age and growth analysis using scales indicated that the brook trout in the Ford River exhibit average or better growth when compared to literature values. Differences in slopes of the regression lines between FCD and FEX in each year revealed significant differences only in 1984, 1986, and 1988. Covariance analysis detected a significant difference between the slopes of the regression lines among pre-operational (1983-1985), transitional (1986-1989), and post-operational (1990-1991) periods. The slopes of the regression lines were greater at FCD for all periods. Brook trout condition was examined using relative weight condition factors (W_r) and regression analysis. A standard weight formula was calculated from 45 literature populations for use in this analysis. Ford River brook trout demonstrated average to below average condition when compared to the species average (W_r 89 - 104). Condition factors declined from 1983 to 1986 and improved from 1987 to 1990 and then declined again in 1991. Length/weight regression analysis revealed no significant differences in the slopes of the regression lines between sites in all years except in 1985. In addition, covariance analysis detected no significant differences in the slopes of the regression lines among pre-operational, transitional, and post-operational years.

VII. PROJECT RATIONALE AND APPROACH

Our research plan is directed at determining the effects of extremely low-level, long term electromagnetic fields (ELF) and gradients produced by the ELF Communications Systems on aquatic plant and animal life. The integrated approach we have taken is to combine the major interrelated and interactive components of aquatic systems (i.e., periphytic algae, aquatic insects, and fish) and to monitor sensitive life history events and community processes critical to the basic structure and function of stream ecosystems. These include: periphyton and stream invertebrate colonization, migration, diversity, trophic level changes in density and biomass, as well as primary productivity; organic matter processing by macroinvertebrates; dynamics of fish population growth, reproduction, and survival; fish behavior including movement patterns of homing and migration. Since many of these processes and events are mutually dependent on one another and interactions are complex, we feel that a holistic approach with a multi-disciplinary effort is imperative.

Our research plan represents an integrated study of stream ecosystems involving three aquatic components for monitoring the potential effects of ELF. These components are: (1) periphytic algae; 2) aquatic insects; and 3) fish. The design incorporates studies of ecosystem properties with studies of behavior and biology of individual species so that any effects of ELF can be quantified at the population, community and ecosystem levels.

We selected stream ecosystems as representative aquatic ecosystems rather than lakes or marshes because; (1) upstream-downstream paired plots on the same system provide less variability than between lake comparisons; (2) migratory behavior is more likely to be important in stream organisms; and (3) our expertise and interests are oriented toward stream ecology.

The effects of ELF on stream ecosystems are tested using a paired plot design of selected sections of the chosen stream, the Ford River. Plots were selected to afford one area of study away from the antenna corridor for use as a control site (FCD), and another area directly under the antenna cable for use as the experimental site (FEX) (Fig. VII.1). These two stream sections constitute our paired plot design. We have intensively studied and sampled the river at these sites since June of 1983, when the final site selections were made. In 1990, additional sites for conducting periphyton, insect, and fish movement studies

Study Area, Dickinson Co., Michigan

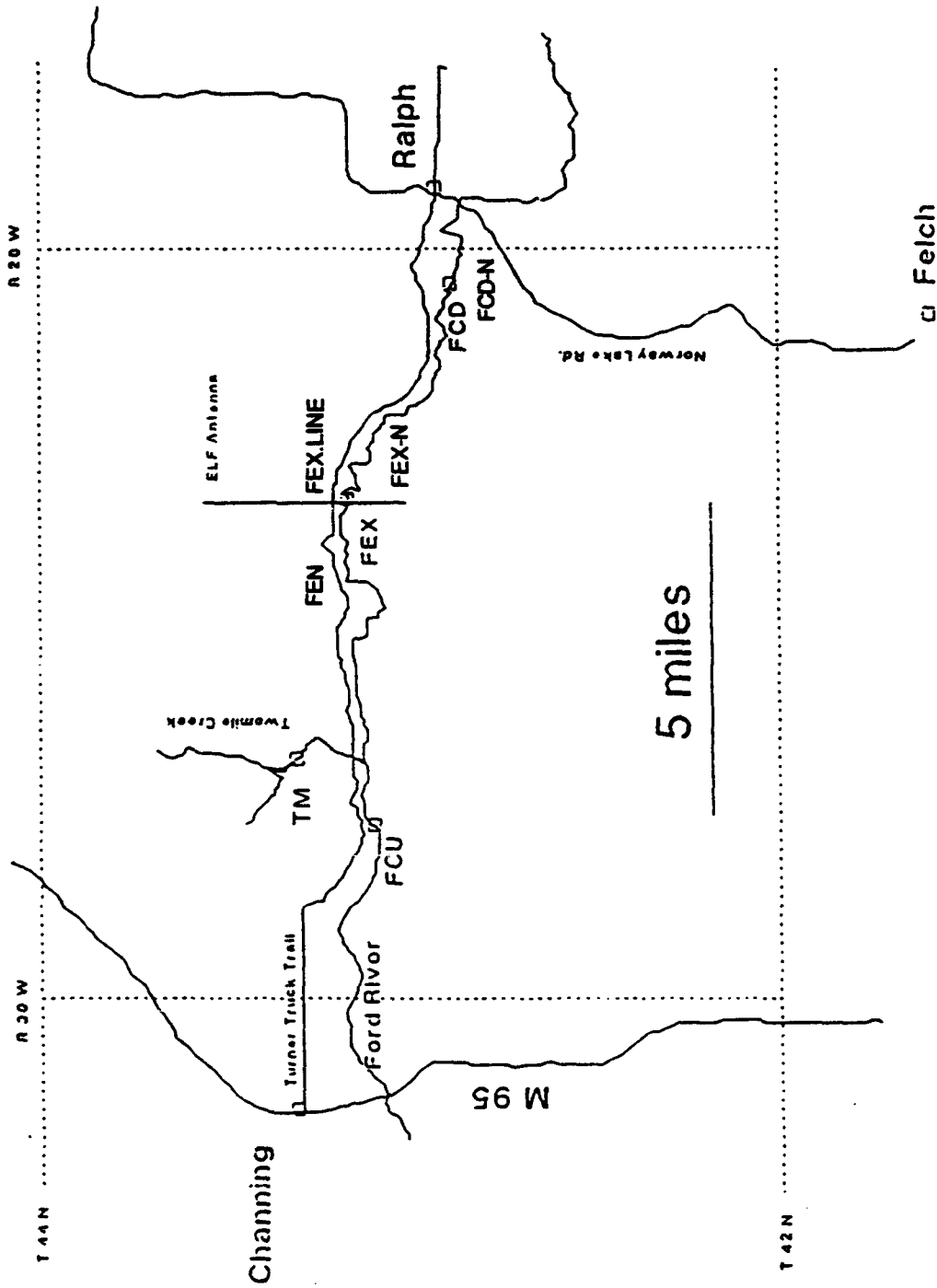


Figure VII.1 ELF Research Sites on the Ford River, Dickinson County, Michigan.

(FEX-N, FCD-N, FEX.Line, and FEN) were chosen to increase the exposure difference to the 10 fold difference called for at the beginning of the study. We also monitor fish movement using the other sites indicated on Fig. VII.1 (FCU, and TM).

For the two primary sites, we are continuously monitoring stream velocity and water depth so the discharge can be calculated. Water temperatures, dissolved oxygen, pH, and solar radiation at the surface and at the stream bottom are also being continuously monitored. We also sample all other chemical parameters required in the RFP.

The data generated from this research should; (1) determine whether the ELF Communications System affects aquatic plant and animal life in stream systems; and (2) contribute to a better understanding of stream processes which will help clarify a number of important aspects of current conceptual models of stream ecosystem structure and function.

VIII. PRESENTATIONS AND PUBLICATIONS FOR 1990-1991

Burton, T. M., D. M. Mullen, and S. L. Eggert. 1991. Effects of extremely low frequency (ELF) fields on the diatom community of the Ford River, Michigan. 3rd annual Midwest Pollution Control Biologists Meeting, April 10-13, Chicago, IL. (To be published in Proceedings of 1991 Midwest Pollution Control Biologists Meeting).

Eggert, S. L., T. M. Burton, and D. M. Mullen. 1991. A comparison of RIA and BACI analysis for detecting pollution effects on stream benthic algal communities. 3rd annual Midwest Pollution Control Biologists Meeting, April 10-13, Chicago, IL. (To be published in Proceedings of 1991 Midwest Pollution Control Biologists Meeting).

IX. OVERALL OBJECTIVES AND SPECIFIC TASK OBJECTIVES

OVERALL OBJECTIVE

Our major objective in this study is to determine the effects of low level, long term electromagnetic fields and gradients produced by the ELF Communication System on aquatic plant and animal life in streams. The study will incorporate studies of ecosystem properties with studies of behavior and biology of individual species so that any effects of ELF will be quantified at the population, community and ecosystem level.

SPECIFIC TASK OBJECTIVES

A. Periphytic Algal Studies

The objectives of the periphytic algal studies are:

- (1) to quantify any changes in species diversity, algal density, and chlorophyll a that might occur as a result of ELF electromagnetic fields;
- (2) to quantify any changes in primary productivity that might occur as a result of ELF; and
- (3) to monitor algal cell volume and chlorophyll a to phaeophytin a ratio, thereby providing an index to physiological stress of periphytic algal cells that might occur as a result of ELF electromagnetic fields.

B. Aquatic Insect Studies

The objectives of the studies of aquatic insects are:

- (1) to quantify any changes in organic matter processing rates that occur as a result of ELF;
- (2) to quantify changes in species richness, individual abundances, and species diversity of the aquatic insect communities associated with leaf pack and inorganic stream bottom substrates;
- (3) to quantify trophic, behavioral, and community level changes in selected species of aquatic insects from an array of functional feeding groups (grazers, collectors, etc.).

C. Fish Studies

The objectives of the studies of the fish are:

- (1) to quantify any changes in the seasonal movement patterns and abundance of the mobile fish community that occur as a result of ELF;
- (2) to quantify any changes in the rate of brook trout movement through the ELF corridor that occur as a result of ELF electromagnetic fields.

X. PROGRESS BY WORK ELEMENT

Element 1 - Conduct Ambient Monitoring Program

Changes from workplan - None.

Objectives

The objectives of this work element are: (1) to provide the background data on physical and chemical parameters needed to correlate observations on biological community dynamics with environmental parameters, and (2) to monitor stream chemistry to determine whether or not observed changes in community structure are related to water quality changes rather than potential ELF radiation induced changes.

Rationale

The chemical and physical factors selected for study are known or suspected to be important factors that may control or influence growth, community structure, or community dynamics of periphyton, insects, and fish. Correlating these variables with biological data may ultimately be useful in predicting the effects of these environmental parameters on the biotic community. Thus, they may be useful in separation of background environmental variability from effects induced by extremely low frequency electromagnetic radiation (ELF). Even though many of these variables may not presently correlate with biological data, unexpected large shifts could lead to dramatic changes in the biotic community. Thus, a second goal of the monitoring program is to document the presence or absence of shifts in chemical or physical variables that could occur if some perturbation such as an unexpected discharge of a pollutant were to occur. The physical and chemical parameters being monitored include the major plant nutrients because of their potential impact on trophic level dynamics (e.g. the various species of nitrogen and phosphorus as well as silica, since diatoms dominate benthic algal production) or parameters that are known to influence insects and fish (e.g. turbidity, dissolved oxygen, discharge and current velocity, water temperature, etc.). Many of the parameters were originally specified in the request for proposal and offer general indices to site productivity or water quality (e.g. specific conductance, alkalinity, hardness, chloride, etc.). Some of the original parameters have been eliminated. These include

total dissolved solids and suspended solids. Neither correlated well with biological parameters. Further, an index to total dissolved solids can be derived from correlations of this parameter with specific conductance, alkalinity, and hardness, while turbidity provides an index to suspended solids (see correlations reported in previous annual reports).

The goal of this annual report will be to present data on all parameters collected since 1983 at our current monitoring sites (the experimental site, FEX, and the control site, FCD) and to document trends and variability in each parameter. We also present statistical comparisons between the two sites in order to document the fact that the two sites do not differ significantly for most of these parameters. We continued to use water quality and other environmental data from these two sites only since they are within 150 meters of the new sites (FEX-New or FEX-N and FCD-New or FCD-N). This distance is not great enough to significantly affect water chemistry, temperature, etc., since riparian vegetation does not change appreciably over this distance nor does any new tributary or obvious source of ground water enter between the old and new sites. Note that our FCD-N and FEX-N are within 10-15 meters of FEX-LINE and the new position of FCD sampling for the aquatic insect portion of the study.

Materials and Methods

Ambient monitoring stations were installed at the experimental site (FEX) and at the control site (FCD) in July, 1983 and were operated until the last week of October. Each year since 1983, these stations were installed in mid-April and were operated through the last week of October. This period represented the period from snow melt in spring until the time of some ice and snow deposition in autumn. After late October, problems were encountered with equipment maintenance and the stations were removed and stored for the winter.

The stations automatically logged on Omnidata data pods (model DP 211) the following parameters:

(1) Photosynthetically active solar radiation (PAR) was measured in a clearing on the stream bank and represented above water solar radiation. PAR was also measured under the water surface, 15 cm above the stream bottom in a riffle to pool transition area and represented below water solar radiation. These measurements were taken using Li-Cor Model LI-192SB underwater quantum sensors. Data were taken at both FEX and FCD through 1986, but measurements were deleted at FCD in 1987 due to failure of one of the data pods. No funds were in the budget for equipment replacement and this, coupled with the expected

relative constancy of solar input between the two sites, led to the decision to cease measurement of solar radiation at one of the sites. This station was repaired for the 1988 season. All four quantum sensors were sent to LI-COR, Inc. for calibration during spring, 1991 and returned to the field in late June.

(2) Dissolved oxygen was monitored using L. G. Nestor Model 8500 portable dissolved oxygen meters with general purpose submersible probes. These meters started to deteriorate in performance in 1987 after five years in the field. We had difficulty maintaining the meters and probes in operating condition especially at FCD. We had these meters repaired during the 1987-88 winter period and ordered new probes. We obtained reliable data for both sites for 1988. The dissolved oxygen meter at FCD was submerged in a flood event during mid-June of 1989. As there were insufficient funds to replace it, the dissolved oxygen data used for this report came from the twice weekly samples taken in the field at both sites. The 28 day mean dissolved oxygen at FEX using this field data was not significantly different (paired-t = -0.117, P = 0.913) than the 28 day means calculated using the ambient monitoring equipment at that site. Thus, we felt that there was no serious loss of data resulting from the temporary loss of the meter. Since the ambient monitoring equipment provided more detailed data (every 30 minutes throughout the season) than the manual field sampling, we replaced the D.O. meter before the start of the 1990 field season, and 30 minute interval data for the field seasons have been collected since that time.

(3) pH was measured using the Altex (Beckman) Monitor II System with specially built long term, gel-filled submersible pH probes from Fisher Scientific. These meters have given us problems in the past. The meters were repaired over the winter of 1987-88 and new probes were ordered. We think that much of our past problems were associated with using the submersed probes for too long a period of time. These probes only have a submersed expected life of 3 or 4 months according to the chemist at Fisher Scientific. By changing the probes as needed over the summer, we have been able to obtain consistent data since 1988.

(4) Air and water temperature were monitored using thermistors. Water depth was monitored using Stevens Type F strip chart recorders. These depth data were used to calculate discharge using a stage height-discharge relationship developed for each of the two sites on the Ford River. Stage (water level) - discharge relationships were determined for each station using Teledyne Gurley pygmy or Price-type current meters using the velocity area technique (Gregory and Walling 1973, p. 129) with at least 20 verticals per cross-section. At least 15 of these

determinations have been made at various stage heights each season to insure that the relationship has not changed from previous years. The extremely low flow associated with the drought conditions in 1988 led to some adjustments of the stage-discharge relationship for the low discharge end of the regression for both sites. Discharge values were highly predictable from stage height data using calculated regressions with R^2 values greater than 0.96 for FEX and 0.97 for FCD.

All automatically acquired data were checked and calibrated by manually determining each parameter at least twice per week. Thus, even if the meters became inoperable, we still had at least two determinations per week for each parameter. For example, the field pH meters were calibrated twice per week with pH 7 and 10 buffers, and field pH meters were checked against an Orion Model 701 specific ion and pH meter in the laboratory at these same times twice each week. Dissolved oxygen meters were calibrated using the azide modification of the Winkler procedure (APHA 1980). Air and water temperature were recorded twice per week using hand-held thermometers, and depth was recorded from the manual staff gauges at each site.

Data from the data pods were transferred from the EPROM chips in the data pods to diskettes using an Omnidata Model 217 reader and an Apple II plus computer. Data, accumulated daily at 30 minute intervals, were read and summarized every two weeks throughout the April to October period. These data are summarized for the 28 day intervals used for periphyton sampling in this report. Daily summary data were supplied to each task investigator (periphyton, insects, fish tasks) as computer printouts.

In addition to the manual determinations of pH, dissolved oxygen, water and air temperature as described above, samples were taken once per week for determination of turbidity, alkalinity, hardness, and specific conductance. These samples were chilled on ice, returned to the field laboratory, and the above parameters were determined within 3-5 hours of collection. Twice per week, samples were taken and frozen for later determination of total phosphorus, soluble reactive phosphorus (samples were placed on ice after collection and were filtered within 3-5 hours of collection), nitrate-N, nitrite-N, ammonium-N, organic-N (total Kjeldahl N minus ammonium), chloride, and dissolved silicate-Si (Si samples were refrigerated instead of being frozen since freezing can cause interference with this procedure). The N, P, Si, and Cl samples were analyzed during the winter months after preparation of the annual report. Thus, there is a one year lag time in

reporting these data. During winter months, samples were taken at one month intervals for all of the parameters discussed above through the winter of 1986-87. This interval was decreased to once every other month in 1987-88 and once every 6 weeks in 1988-89 and 1989-90, since the expense of taking the samples is prohibitive given the minimal amount of biological data collected during the winter months.

All chemical analyses followed procedures outlined in Standard Methods (APHA 1980) or approved techniques of the U.S. Environmental Protection Agency (U.S. EPA 1979).

Stream velocity was also recorded for the periphyton samplers (see Element 2) using the Gurley pygmy meters about once per week. These data were used to adjust the positions of the periphyton samplers in the stream so that samplers at each site were exposed to comparable flow regimes.

Statistical comparisons included paired t-tests between the two sites for each parameter, correlations between the two sites, and correlations between the chemical and physical parameters. Unless otherwise indicated, we accepted as significant $p < 0.05$.

Procedures for calculating ELF exposures to earth electric fields and to magnetic flux were explained in the last annual report. Essentially, these data were calculated on the basis of hours of operation from the logs of the antenna operation and from site measurements of earth electric fields and magnetic flux data from IITRI.

Results and Discussion

A. Field Chemistry

The dissolved oxygen (DO) data for 1990-91 (Table 1.1) corroborated the highly predictable pattern observed at both sites for all previous years of the project with winter highs and summer lows (Fig. 1.1). In general, winter values were 11 mg/L or higher and summer values never dropped below 7 mg/L (Fig. 1.1). Since cold water contains more dissolved oxygen at saturation than does warm water, one would expect this type of pattern if the water in the river is near saturation throughout the year. The Ford River was typically 5-15 % undersaturated at each site, and DO has shown high negative correlations with temperature at each site ($r = -0.93$ and -0.95 at FCD and FEX respectively, $p < 0.01$ at both sites). There was a significant ($p < 0.01$) correlation ($r = 0.99$) in dissolved oxygen values between the two sites for 1990-91 (Table 1.2)

Table 1.1 pH and Dissolved Oxygen (mg/L) for the Ford River for 1991.
Values are Means \pm S.E., N in Parentheses.

Date	pH		Dissolved Oxygen	
	Experimental (FEX)	Control (FCD)	Experimental (FEX)	Control (FCD)
10/1/90	7.93 \pm 0.07 (9)	7.94 \pm 0.05 (9)	9.74 \pm 0.26 (9)	9.68 \pm 0.25 (9)
10/28/90	7.85 \pm 0.04 (9)	7.87 \pm 0.04 (9)	11.41 \pm 0.32 (9)	11.38 \pm 0.28 (9)
12/10/90	7.65 \pm 0.00 (2)	7.67 \pm 0.00 (2)	13.03 \pm 0.00 (2)	12.73 \pm 0.00 (2)
1/19/91	7.35 \pm 0.00 (2)	7.50 \pm 0.00 (2)	13.20 \pm 0.00 (2)	12.80 \pm 0.00 (2)
3/2/91	7.35 \pm 0.00 (2)	7.45 \pm 0.00 (2)	12.10 \pm 0.00 (2)	11.50 \pm 0.00 (2)
4/22/91	7.70 \pm 0.00 (2)	7.80 \pm 0.00 (2)	12.03 \pm 0.00 (2)	11.73 \pm 0.00 (2)
5/20/91	7.64 \pm 0.07 (9)	7.60 \pm 0.02 (29)	10.25 \pm 0.37 (22)	10.13 \pm 0.25 (22)
6/17/91	7.92 \pm 0.02 (29)	8.00 \pm 0.01 (27)	8.46 \pm 0.27 (14)	8.21 \pm 0.09 (29)
7/15/91	7.97 \pm 0.02 (28)	7.91 \pm 0.03 (23)	8.11 \pm 0.17 (13)	8.26 \pm 0.10 (26)
8/12/91	8.07 \pm 0.01 (24)	8.04 \pm 0.04 (17)	8.42 \pm 0.12 (18)	8.27 \pm 0.17 (14)
9/9/91	8.06 \pm 0.01 (21)	7.99 \pm 0.03 (9)	8.88 \pm 0.14 (23)	8.64 \pm 0.14 (27)

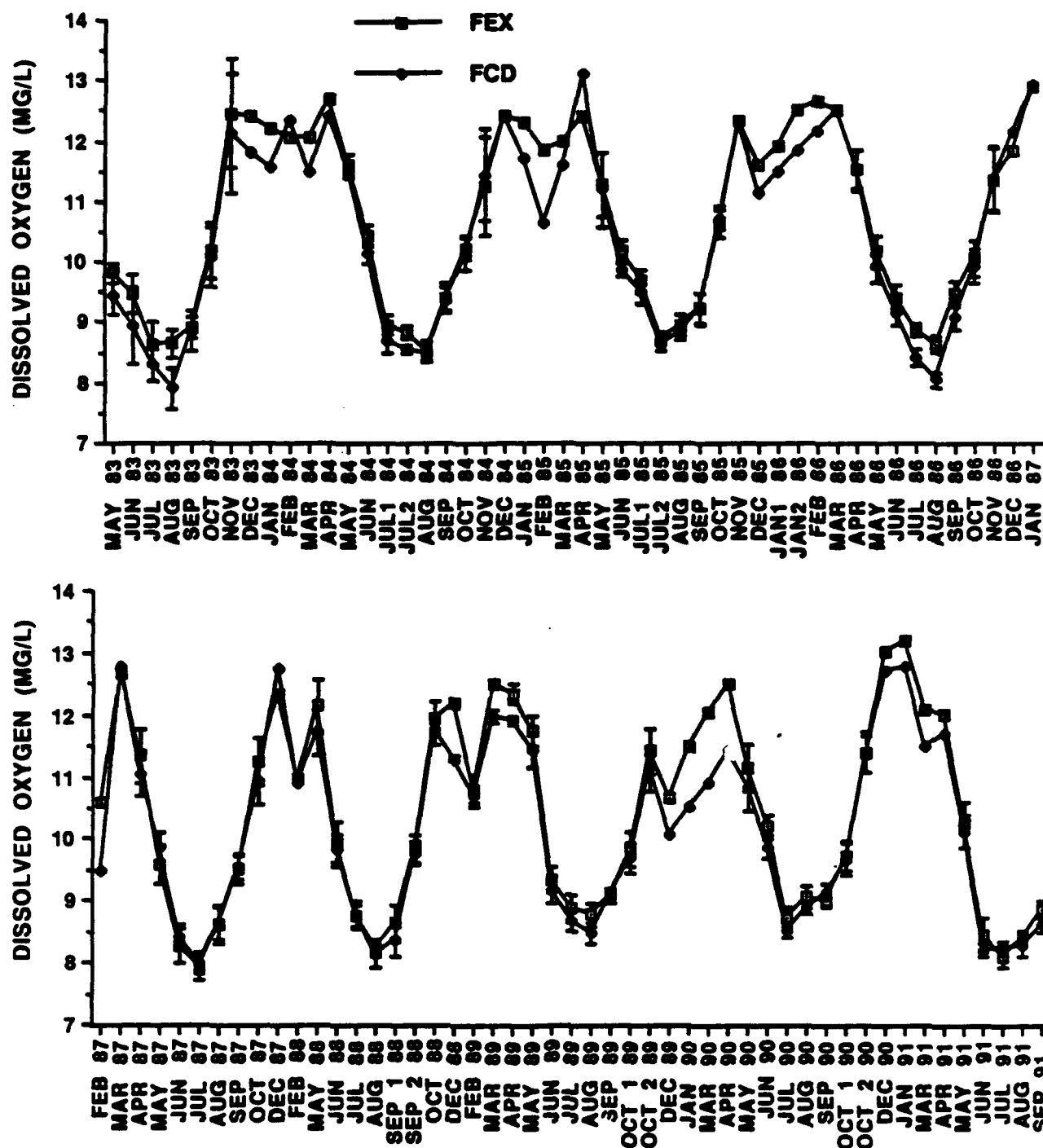


FIGURE 1.1 MEAN DISSOLVED OXYGEN LEVELS (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1991.

Table 1.2 Results of Paired t-tests and correlations between Experimental (FEX) and Control (FCD) sites for water chemical constituents and ambient parameters for 1990-1991.

Parameter	df	Paired t-value	Significance	Correlation coefficient	Significance
Conductivity	10	-0.362	NS	0.925	p < 0.01
Hardness	10	-2.941	p < 0.05	0.999	p < 0.01
Alkalinity	10	-1.304	NS	0.877	p < 0.01
Turbidity	10	-1.431	NS	0.944	p < 0.01
pH	10	-1.152	NS	0.970	p < 0.01
Dissolved Oxygen	10	3.454	p < 0.01	0.996	p < 0.01
Water Temperature	10	-1.585	NS	0.998	p < 0.01

as illustrated by Fig 1.1 and Table 1.1. We also reported this high degree of correlation for all data collected prior to 1990-91 ($r = 0.98$) (Table 1.3). In 1990-91, there was a significant difference between the two sites (Table 1.2), even though there had not been significant differences between the two sites for data collected in 1988 (see the 1988 annual report). In the 1988 report, we hypothesized that differences in dissolved oxygen between the sites reported prior to 1988 were due to a researcher bias for consistently visiting one site first during the sampling trip. Altering the site that was visited first seemed to eliminate this difference in 1988, but has not worked since then. In all years in which there has been a difference between the 2 sites, FEX has had the higher D.O. (Fig. 1.1). The reason for this difference is not known but may be caused by many factors (ie. turbulent water upstream of FEX that is not present at FCD). Regardless of the cause, when differences have occurred between the two sites in the past, they have been small (Fig. 1.1) with values at each site well above DO levels of 6.0 mg/L needed for maintenance of trout populations in good condition (Mckee and Wolf 1963).

The 1990-91 pH data for the two sites followed the previous pattern of summer highs and winter lows (Fig. 1.2, Table 1.1), probably related to higher levels of primary production in the summer (see Element 2) coupled with lower stream discharge, and higher values for alkalinity (pH was significantly ($p < 0.05$) correlated with all these parameters). The most highly correlated parameters with pH were water temperature with r 's greater than 0.72 at both sites and discharge with r 's greater than -0.67 at both sites. The pH values at the two sites were significantly correlated with each other in 1990-91, and there were no significant differences between sites (Table 1.2) as has been true for all data collected over the course of the study (Table 1.3). Automatically acquired data for the two sites since 1988 has been consistent in quality unlike the inconsistent data collected in 1986 and 1987. The changes in procedure described in the methods section resulted in this consistent data from 1988 through 1991.

Alkalinity and hardness followed similar trends for the two sites (Table 1.4 and Figs. 1.3, 1.4) with high values occurring during times of low flows, and low values occurring during times of high flows (Fig. 1.5, 1.6). These parameters are significantly ($p < 0.01$) positively correlated with specific conductance ($r = 0.74$ or greater). As expected, hardness and alkalinity are highly correlated with each other ($r = 0.99$, $p < 0.01$) at both sites, and it would be feasible to drop one of these two analyses from our sampling program. We will eliminate hardness analyses

Table 1.3 Results of Paired t-tests and correlations between Experimental (FEX) and Control (FCD) sites for water chemical constituents and ambient parameters from June 1983 to September 1991.

Parameter	df	Paired t-value	Significance	Correlation coefficient	Significance
Conductivity	95	-0.215	NS	0.916	p < 0.01
Hardness	96	-4.356	p < 0.01	0.982	p < 0.01
Alkalinity	96	-2.704	p < 0.01	0.957	p < 0.01
Turbidity	95	-2.174	p < 0.05	0.741	p < 0.01
pH	90	-3.200	NS	0.932	p < 0.01
Dissolved Oxygen	95	7.227	p < 0.01	0.976	p < 0.01
Water Temperature	95	1.965	p = 0.05	0.995	p < 0.01

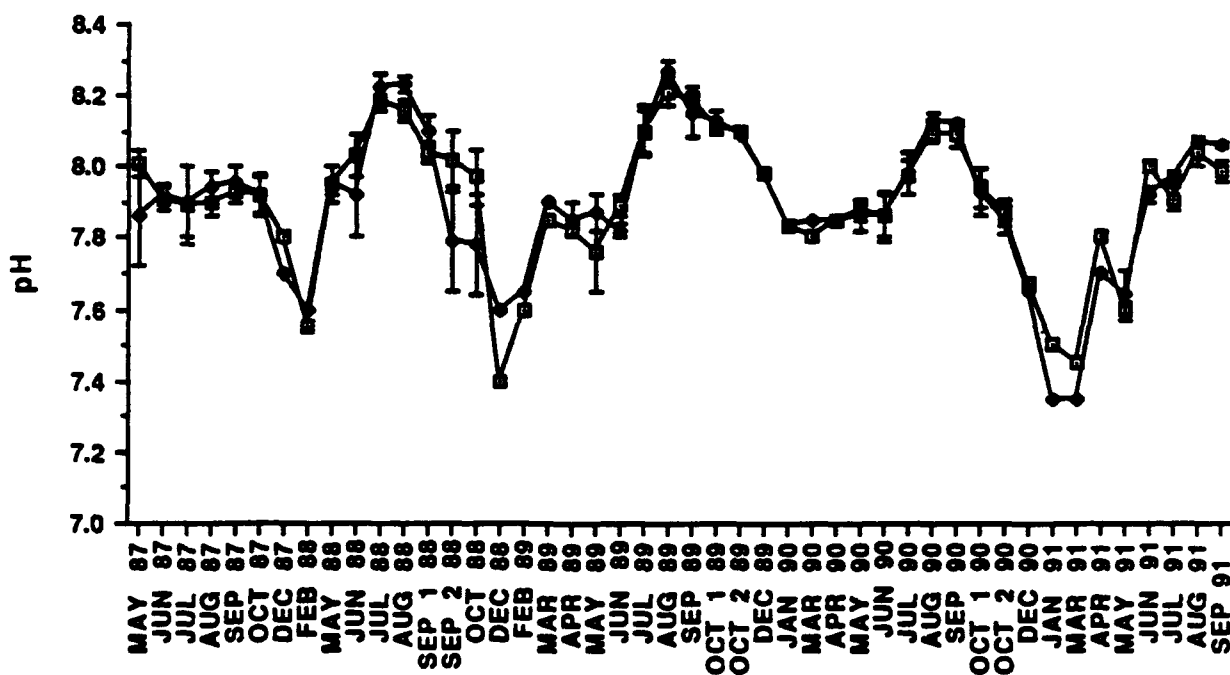
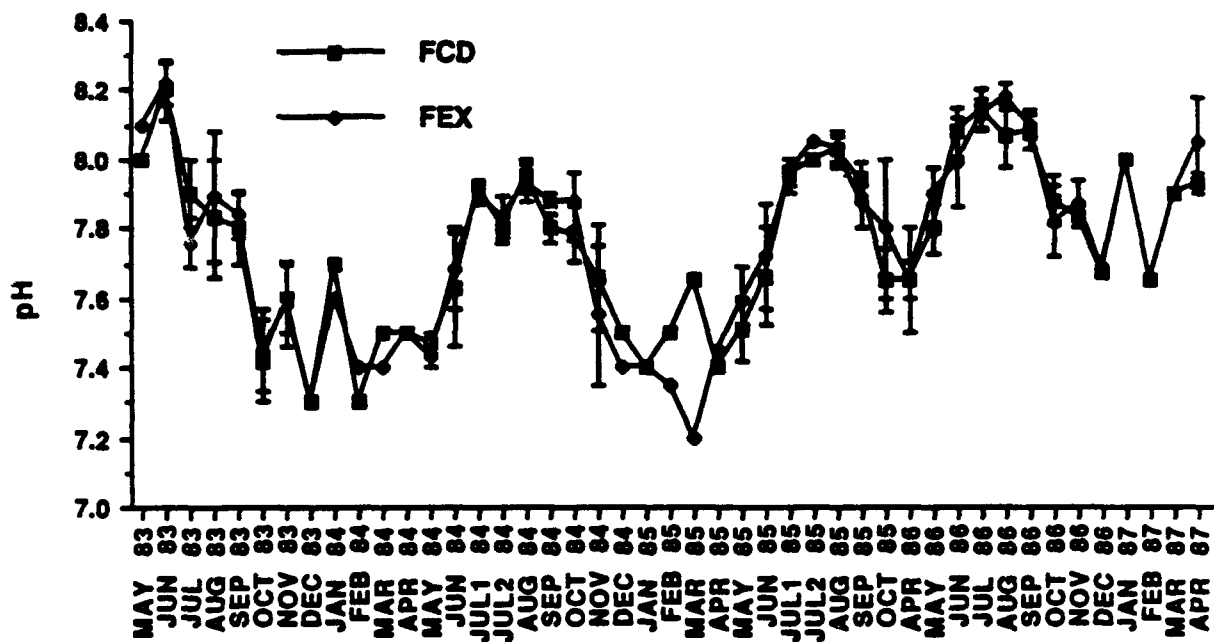


FIGURE 1.2 MEAN pH LEVELS (\pm S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1991.

Table 1.4 Alkalinity and Hardness (mg CaCO₃/L) for the Ford River.
Values are Means \pm S.E., N in Parentheses.

Date	Alkalinity		Hardness	
	Experimental (FEX)	Control (FCD)	Experimental (FCX)	Control (FCD)
10/1/90	145 \pm 5 (5)	147 \pm 4 (5)	168 \pm 5 (5)	170 \pm 5 (5)
10/29/90	127 \pm 11 (5)	130 \pm 11 (5)	149 \pm 8 (4)	152 \pm 10 (4)
12/10/90	118 \pm 0 (2)	116 \pm 0 (5)	150 \pm 0 (2)	153 \pm 0 (2)
1/19/91	145 \pm 0 (2)	143 \pm 0 (2)	182 \pm 0 (2)	182 \pm 0 (2)
3/2/91	163 \pm 0 (2)	166 \pm 0 (2)	196 \pm 0 (2)	194 \pm 0 (2)
4/22/91	84 \pm 0 (2)	127 \pm 0 (2)	152 \pm 0 (2)	156 \pm 0 (2)
5/20/91	94 \pm 4 (5)	99 \pm 4 (5)	115 \pm 4 (5)	120 \pm 3 (5)
6/17/91	113 \pm 6 (5)	117 \pm 7 (5)	132 \pm 6 (5)	135 \pm 6 (5)
7/15/91	128 \pm 5 (5)	130 \pm 5 (5)	149 \pm 5 (5)	149 \pm 6 (5)
8/12/91	151 \pm 6 (5)	151 \pm 5 (5)	169 \pm 3 (5)	169 \pm 3 (5)
9/9/91	163 \pm 3 (5)	163 \pm 3 (5)	178 \pm 2 (5)	179 \pm 2 (5)

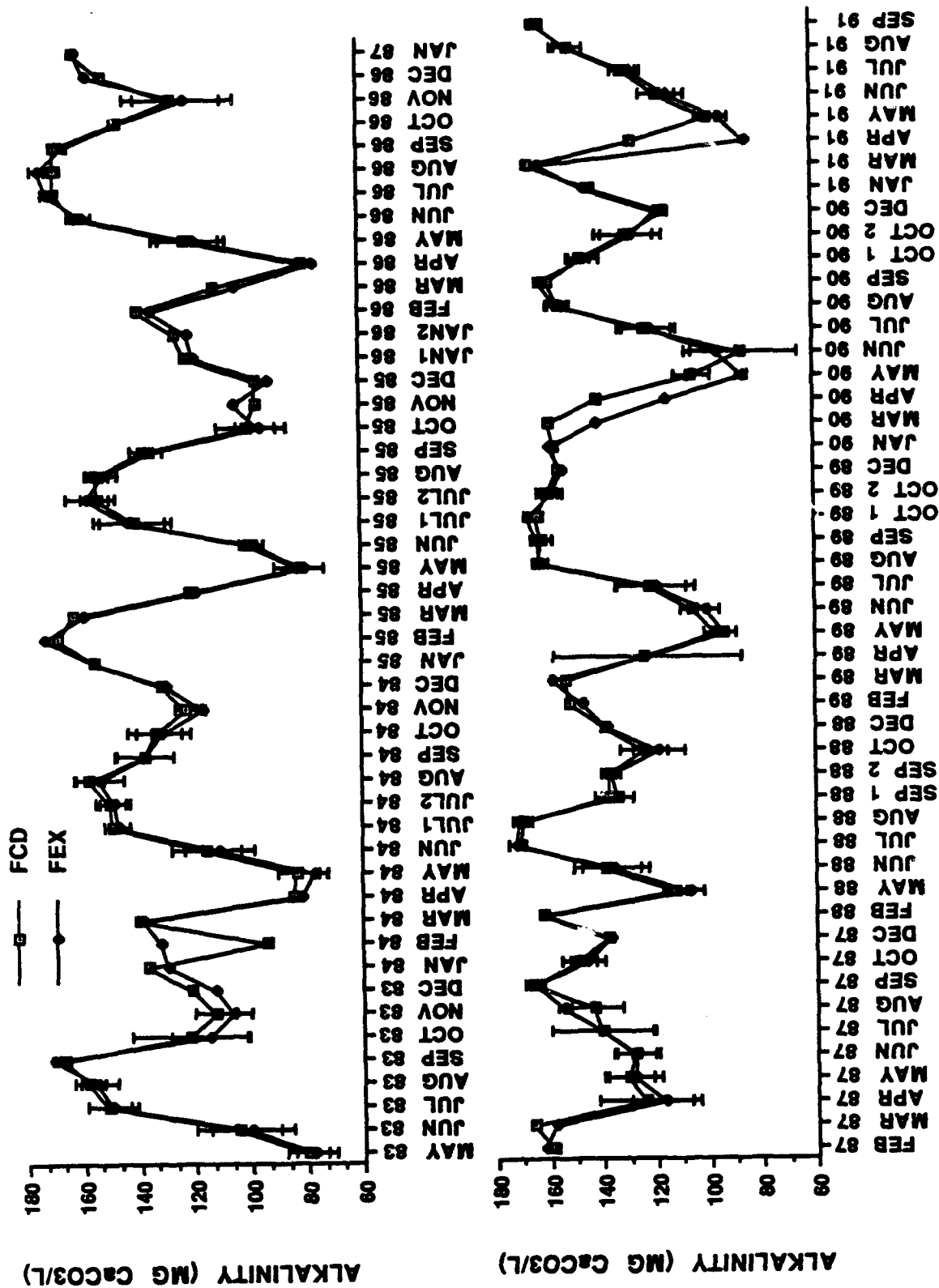


FIGURE 1.3 MEAN ALKALINITY LEVELS (S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1991.

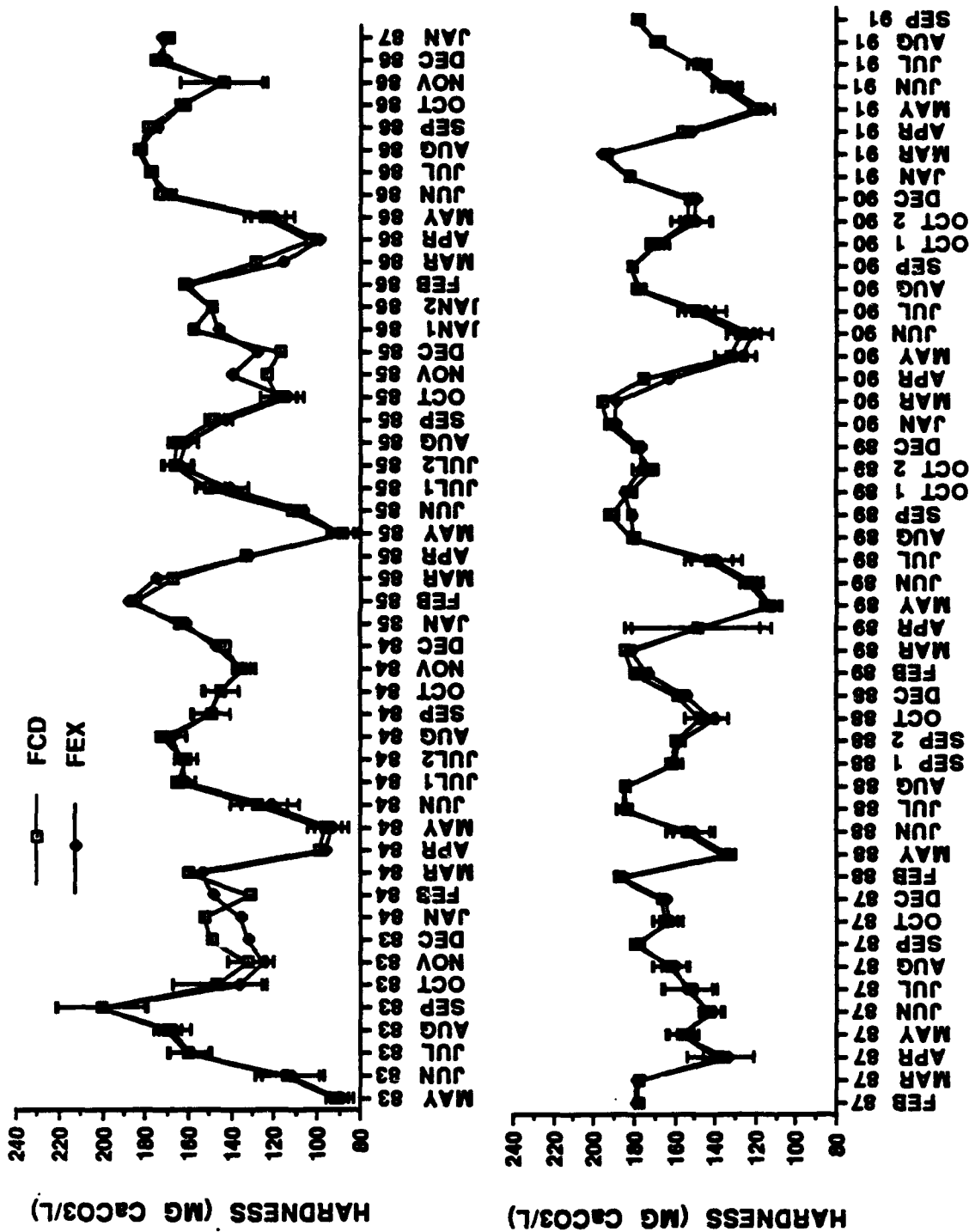


FIGURE 1.4 MEAN HARDNESS LEVELS (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1991.

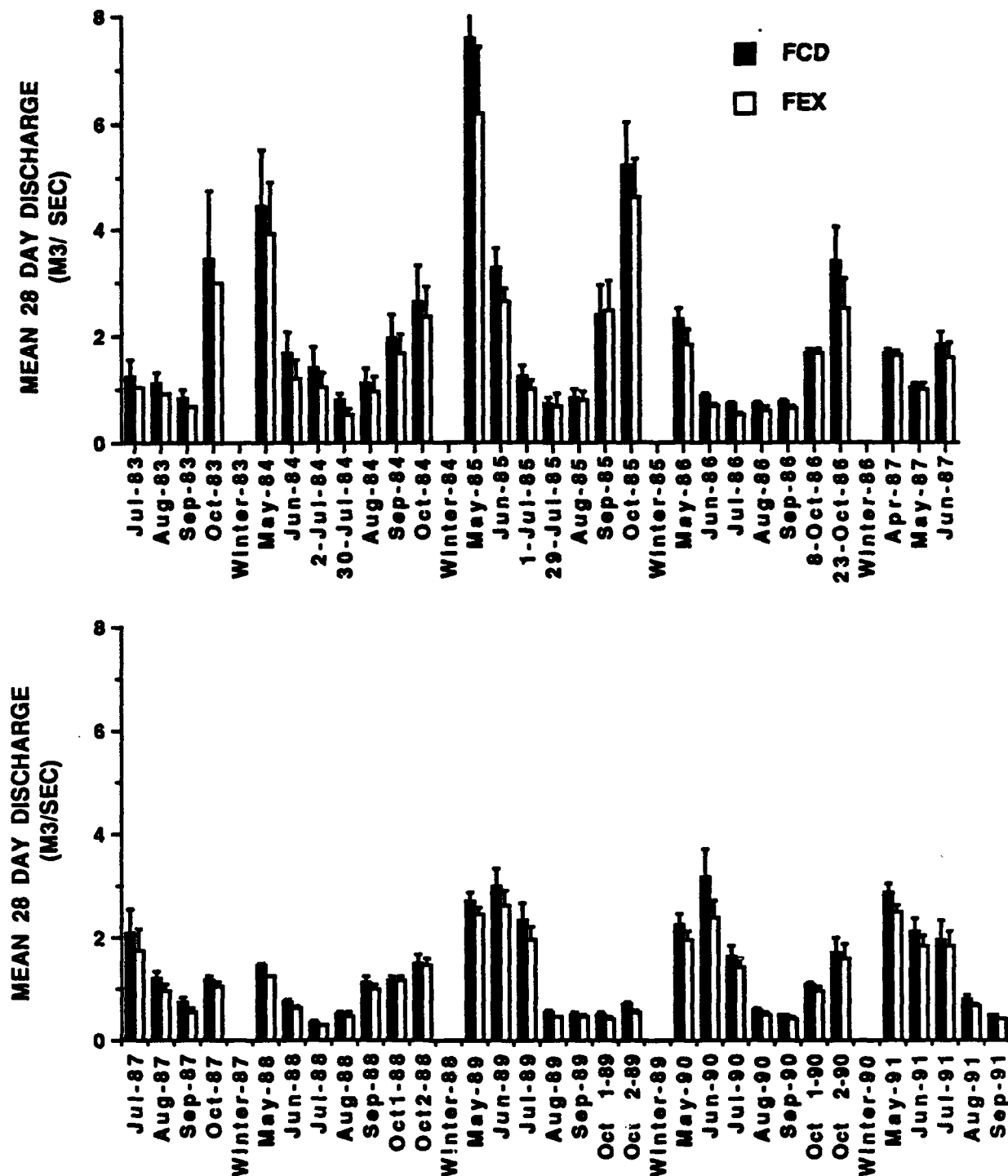


FIGURE 1.5 MEAN DISCHARGE LEVELS (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1991.

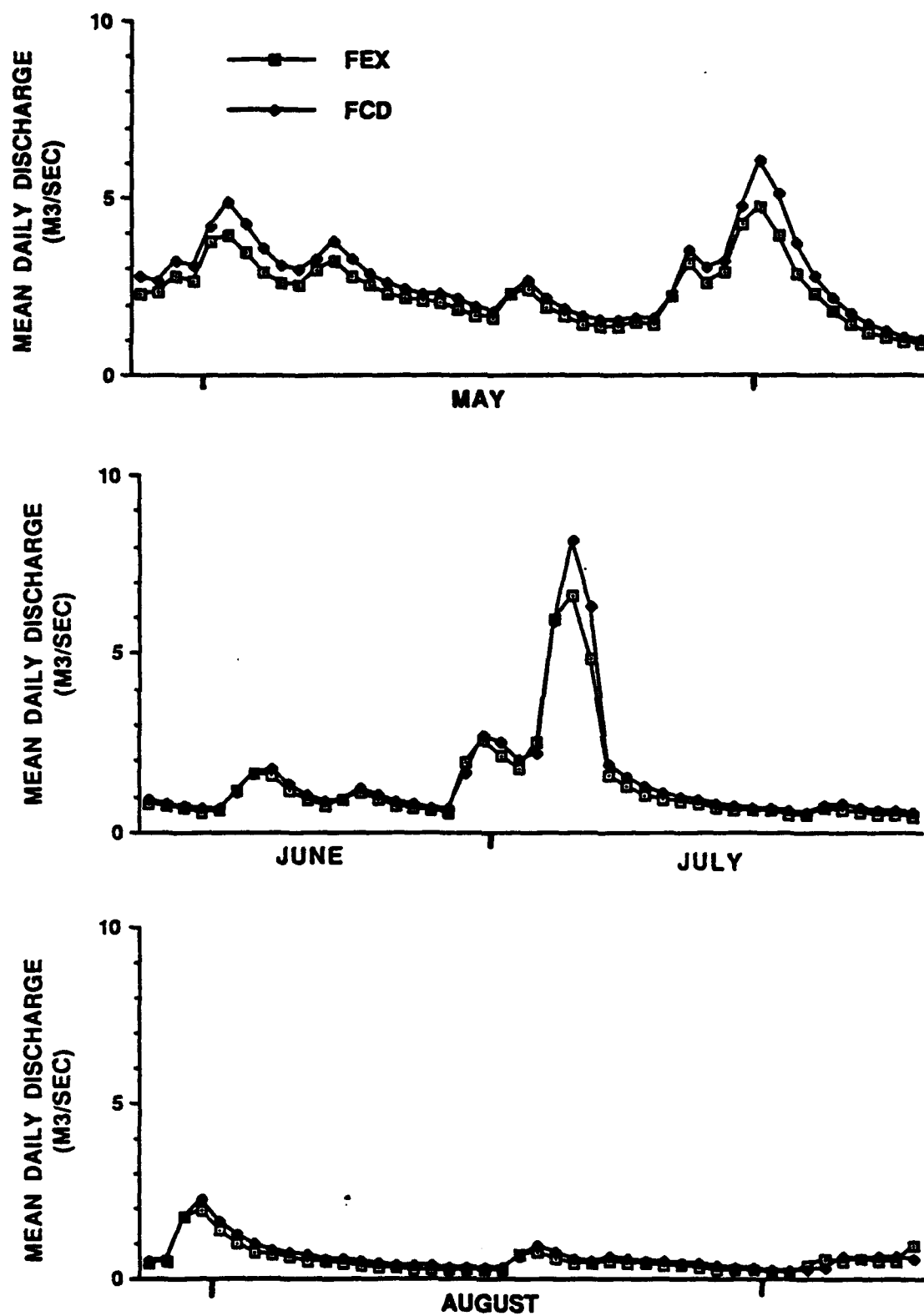


FIGURE 1.6 DAILY DISCHARGE MEANS FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES FOR 1991.

in 1992. Alkalinity at FCD was highly correlated with alkalinity at FEX both in 1990-91 ($r=0.88$, $p<0.01$) and when all data since 1983 are included ($r=0.96$, $p<0.01$). There was no significant difference between the sites (Table 1.2, Table 1.3). Hardness was even more highly correlated between the sites, but there was a significant difference between the sites (Table 1.2, Table 1.3). Hardness at FCD was slightly, but significantly, greater than at FEX (Fig. 1.4). This increase may be related to the expected increase in cations in a downstream direction.

Conductivity (Fig. 1.7, Table 1.5) follows the same seasonal pattern as alkalinity (Fig. 1.3) and hardness (Fig. 1.4), with high conductivities occurring in months with low flows and lower conductivities occurring in the months with high discharge. Conductivity values at FEX were highly correlated ($r=0.93$, $p<0.01$) with conductivity values at FCD during 1990-91 (Table 1.2) and for all data collected since 1983 ($r=0.92$, $p<0.01$) (Table 1.3). There were no significant differences between sites (Tables 1.2, 1.3).

Turbidity (Table 1.5, Fig. 1.8) remained relatively low reflecting the excellent water quality of the Ford River. Turbidity at FEX was highly correlated with turbidity at FCD ($r=0.94$, $p<0.01$), and there were no significant differences between the two sites for 1990-91 (Table 1.2). Based on the 1983-91 data, the sites were correlated ($r=0.74$, $p<0.01$) but were significantly different at the $p<0.05$ level (Table 1.3).

B. Nutrient Chemistry

Nutrient chemistry samples are frozen and analyzed during the following winter. Thus, data in this annual report do not include data for 1991.

Trends in total phosphorus prior to 1987 were not obvious because of the high variability of this constituent (Fig. 1.9), although values appeared to be somewhat higher in the winter, spring, and summer in 1986 at FEX than they were in previous years. The data for 1987-89 were much more consistent between sites (with a few exceptions) than had previously been the case. We have no explanation for this increase in consistency. In 1990, values between the two sites returned to some inconsistency with FCD values being higher than FEX values on some occasions (Table 1.6, Fig. 1.9). Even with the inconsistencies, the concentrations at both sites are relatively low and are characteristic of values of total P for the eastern U.S. reflecting land use that is 50 to 90 % forest (see Omernik 1977, he placed

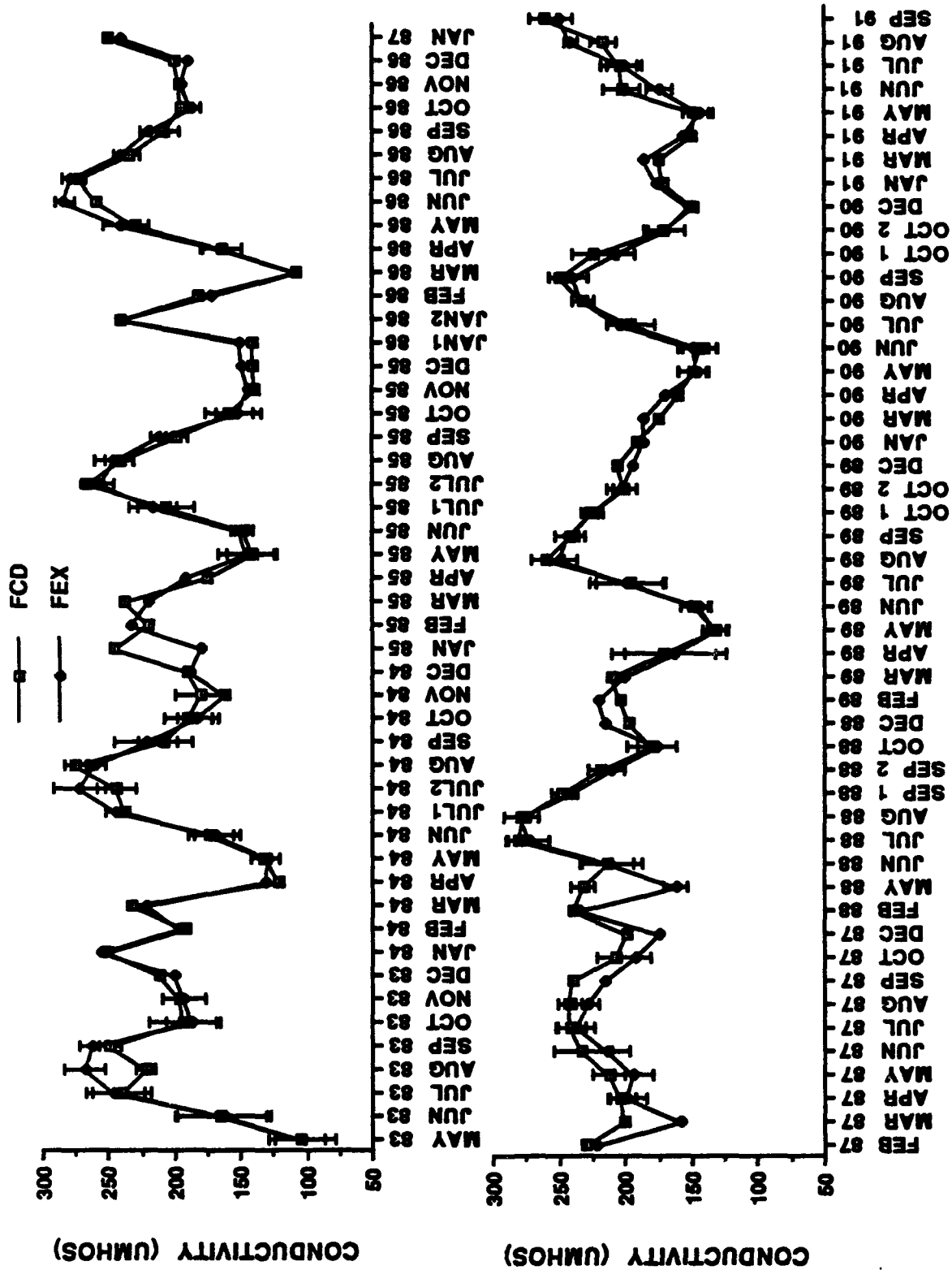


FIGURE 1.7 MEAN CONDUCTIVITY LEVELS (\pm S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1991.

Table 1.5 Conductivity ($\mu\text{mhos/cm}$) and Turbidity (NTU's) for the Ford River.
Values are Means \pm S.E., N in parentheses.

Date	Conductivity		Turbidity	
	Experimental (FEX)	Control (FCD)	Experimental (FEX)	Control (FCD)
10/1/90	207 \pm 14 (5)	222 \pm 16 (5)	1.2 \pm 0.1 (5)	1.2 \pm 0.1 (5)
10/29/90	169 \pm 13 (5)	171 \pm 15 (5)	0.8 \pm 0.1 (5)	0.9 \pm 0.0 (5)
12/10/90	151 \pm 0 (2)	148 \pm 0 (5)	0.8 \pm 0.0 (2)	0.8 \pm 0.0 (2)
1/19/91	176 \pm 0 (2)	171 \pm 0 (2)	0.9 \pm 0.0 (2)	0.9 \pm 0.0 (2)
3/2/91	185 \pm 0 (2)	175 \pm 0 (2)	1.8 \pm 0.0 (2)	1.8 \pm 0.0 (2)
4/22/91	155 \pm 0 (2)	149 \pm 0 (2)	1.5 \pm 0.0 (2)	1.6 \pm 0.0 (2)
5/20/91	143 \pm 9 (5)	146 \pm 10 (5)	0.9 \pm 0.2 (5)	0.9 \pm 0.2 (5)
6/17/91	174 \pm 10 (5)	202 \pm 14 (5)	1.2 \pm 0.3 (5)	1.2 \pm 0.2 (5)
7/15/91	200 \pm 13 (5)	204 \pm 13 (5)	1.4 \pm 0.2 (5)	1.3 \pm 0.1 (5)
8/12/91	241 \pm 5 (5)	217 \pm 10 (5)	1.7 \pm 0.2 (5)	1.7 \pm 0.2 (5)
9/9/91	249 \pm 10 (5)	217 \pm 11 (5)	1.7 \pm 0.1 (5)	1.7 \pm 0.2 (5)

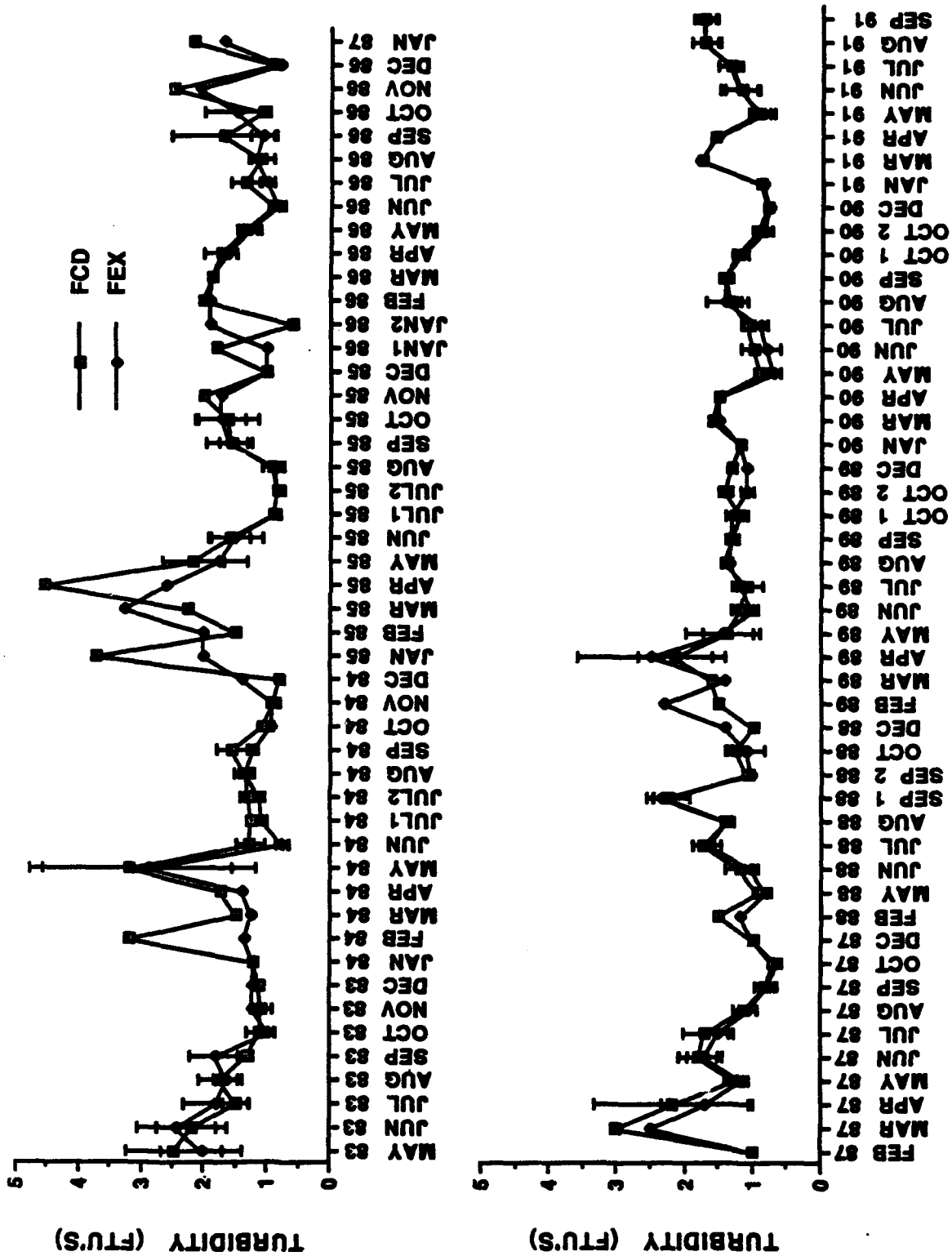


FIGURE 1.8 MEAN TURBIDITY LEVELS (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1991.

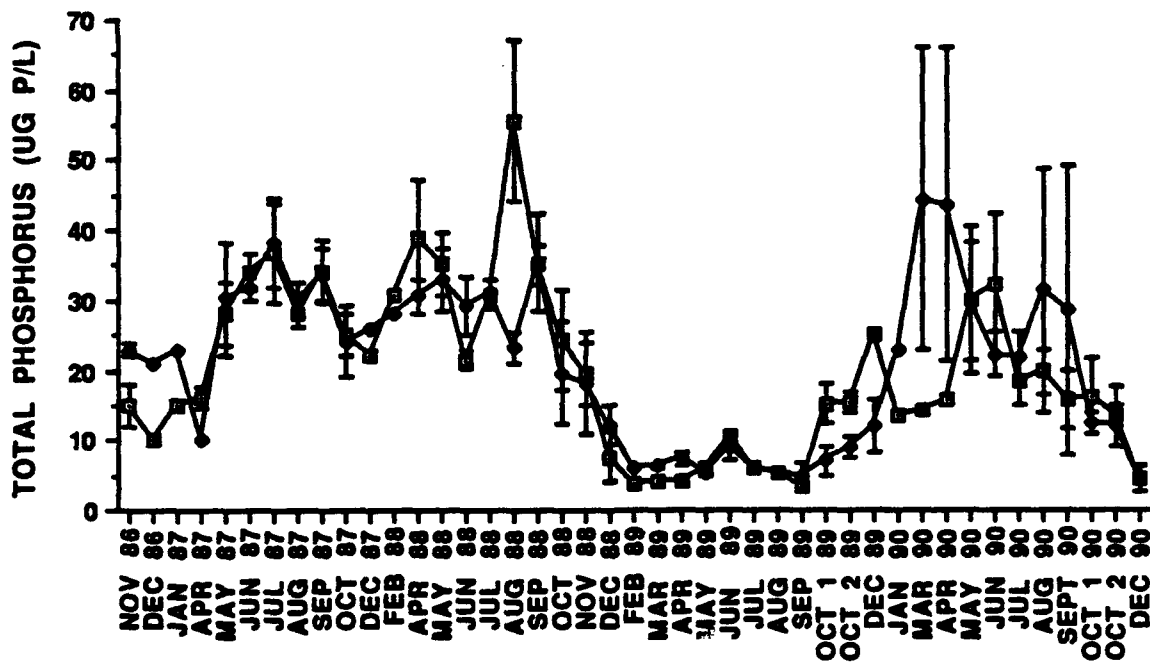
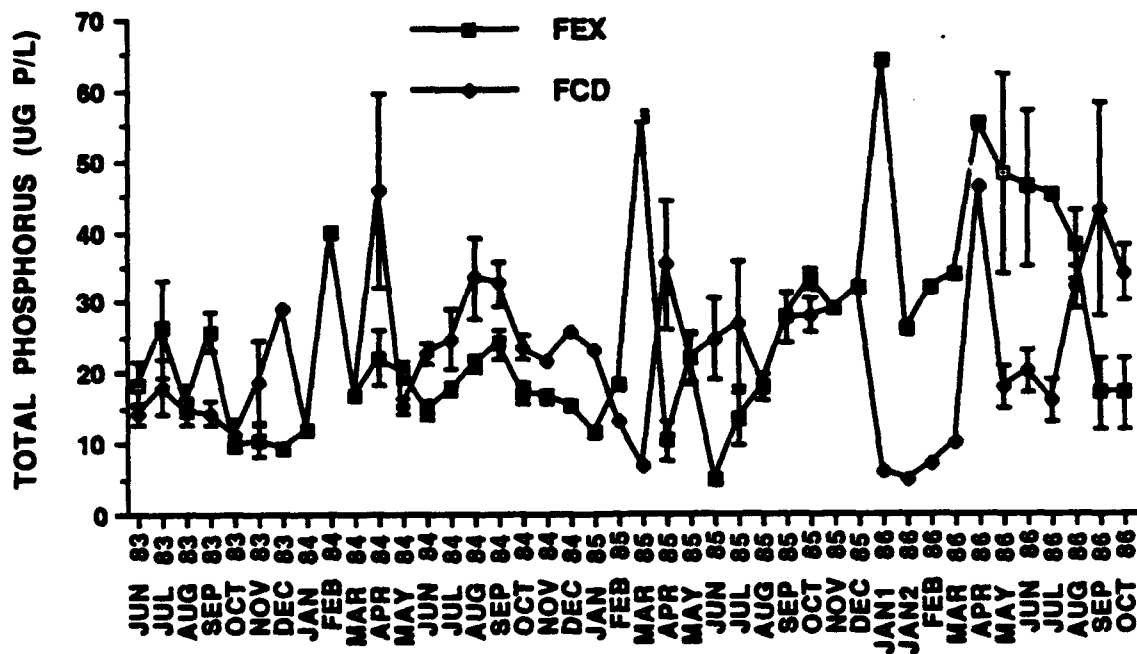


FIGURE 1.9 MEAN TOTAL PHOSPHORUS CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1990.

Table 1.6 Soluble Reactive Phosphorus ($\mu\text{g P/L}$) and Total Phosphorus ($\mu\text{g/L}$) for the Ford River for 1990. Values are Means \pm S.E., N in Parentheses.

Date	Soluble Reactive Phosphorus		Total Phosphorus	
	Experimental (FEX)	Control (FCD)	Experimental (FEX)	Control (FCD)
1/22/90	2.40 (1)	2.40 (1)	13.50 (1)	22.80 (1)
3/4/90	2.35 \pm 0.05 (2)	2.20 \pm 0.20 (2)	14.30 \pm 0.80 (2)	44.35 \pm 21.55 (2)
4/16/90	2.50 \pm 0.20 (2)	2.35 \pm 0.35 (2)	15.85 \pm 0.75 (2)	43.55 \pm 22.35 (2)
5/14/90	4.01 \pm 0.32 (9)	4.40 \pm 0.53 (9)	29.96 \pm 10.37 (9)	29.78 \pm 8.58 (9)
6/11/90	5.52 \pm 0.53 (9)	5.83 \pm 0.82 (9)	32.17 \pm 10.23 (9)	22.26 \pm 3.06 (9)
7/9/90	4.34 \pm 0.53 (9)	5.18 \pm 1.42 (9)	18.49 \pm 3.38 (9)	21.76 \pm 3.75 (9)
8/6/90	2.54 \pm 0.16 (8)	2.50 \pm 0.15 (8)	19.70 \pm 3.21 (8)	31.30 \pm 17.34 (8)
9/4/90	2.74 \pm 0.36 (7)	2.70 \pm 0.47 (7)	15.81 \pm 4.17 (7)	28.50 \pm 20.55 (7)
10/1/90	3.42 \pm 0.21 (9)	3.41 \pm 0.26 (9)	16.23 \pm 5.38 (9)	12.23 \pm 1.55 (9)
10/28/90	4.98 \pm 1.04 (9)	5.29 \pm 1.55 (9)	13.32 \pm 4.19 (9)	12.01 \pm 3.07 (9)
12/10/90	8.85 \pm 4.25 (2)	11.60 \pm 6.00 (2)	4.50 \pm 1.70 (2)	4.50 \pm 1.70 (2)

Michigan in the eastern U.S. region). Land use in the Ford River watershed is dominated by short rotation forestry with Populus tremuloides (quaking aspen) being the predominant forest species. Total P at FEX was not significantly correlated with total P at FCD in 1990 (Table 1.7), as has been the case in all past years except 1987. There were no significant differences between the two sites in 1990 continuing the trend reported for the data from 1983 through 1989 (Table 1.8). Total P is positively correlated with organic N ($r=0.45$ for FEX and 0.37 for FCD) and negatively correlated with Si ($r = -0.34$ and -0.38 for FEX and FCD) ($p<0.05$). These correlations are not very robust but are reasonable, since both total P and organic N are primarily associated with particulates which are usually directly correlated with discharge while Si is usually inversely correlated with discharge.

Soluble reactive phosphorus (SRP) consistently stayed below $10 \mu\text{g P/L}$ except at FCD in late 1986 (Fig. 1.10, Table 1.6). There did appear to be an increase at FCD in 1986 that did not occur at FEX (Fig. 1.10), but this apparent trend towards increased P at the control site has not occurred again for data collected through 1990. In fact, there has been no significant difference in SRP between FCD and FEX since 1986, and SRP at FCD has been highly correlated with SRP at FEX; this trend continued in 1989-90 (Table 1.7) and reflects the trend overall when data from 1983 through 1990 are analyzed (Table 1.8). The increased SRP values in late 1986 may be a delayed response to the 1985 forest clearcut, discussed in the following paragraph. As with total phosphorus, soluble reactive phosphorus has been more consistent between the sites since 1986, although some inconsistencies occurred in the spring of 1989 and in December 1990 (Fig. 1.10). The SRP values for FEX and FCD (Fig. 1.10, Table 1.6) were characteristic of values for land that is 50 to 90 % forested according to Omernik (1977).

Nitrate-N, nitrite-N, and ammonium-N values have been reasonably similar at FEX and FCD since 1983, and this trend continued in 1989-90 (Figs. 1.11, 1.12, 1.13, Table 1.9). There was a divergence in nitrate-N values between the two sites in 1985 (Fig. 1.11), but nitrate-N was comparable for other time periods. One possibility for this difference is that leaching occurred from a small area of forest just upstream of FCD that was clearcut in 1985. This forest practice is known to lead to high nitrate losses in the first year or so after cutting for some northern hardwoods forests similar to the forests along the Ford River (Bormann and Likens 1979, Vitousek et al. 1982). In order to better document the effect of watershed changes on nutrient losses, we are in the process of preparing an

Table 1.7 Results of Paired t-tests and correlations between Experimental (FEX) and Control (FCD) sites for nutrient chemistry parameters for 1989-1990.

Parameter	df	Paired t-value	Significance	Correlation coefficient	Significance
Organic Nitrogen	10	0.993	NS	0.742	p < 0.05
Inorganic Nitrogen	10	2.070	NS	0.994	0.01
Ammonium-N	10	0.962	NS	0.917	0.01
Nitrate-N	10	1.036	NS	0.975	0.01
Nitrite-N	10	2.067	NS	0.967	0.01
Total Phosphorus	10	-1.883	NS	0.287	NS
Soluble Reactive Phosphorus	10	-1.512	NS	0.993	0.01
Silicate	10	3.699	p < 0.01	0.996	0.01
Chloride	10	4.285	p < 0.01	0.847	p < 0.05

Table 1.8 Results of Paired t-tests and correlations between Experimental (FEX) and Control (FCD) sites for nutrient chemistry parameters from June 1983 to September 1990.

Parameter	df	Paired t-value	Significance	Correlation coefficient	Significance
Organic Nitrogen	73	-2.423	p < 0.05	0.731	p < 0.01
Inorganic Nitrogen	84	-1.435	NS	0.796	p < 0.01
Ammonium-N	84	0.922	NS	0.396	p < 0.01
Nitrite-N	85	2.555	p = 0.01	0.804	p < 0.01
Total Phosphorus	85	0.256	NS	0.271	p < 0.05
Soluble Reactive Phosphorus	79	-1.870	NS	0.352	p < 0.01
Silicate	87	1.083	NS	0.928	p < 0.01
Chloride	85	4.812	p < 0.01	0.905	p < 0.01

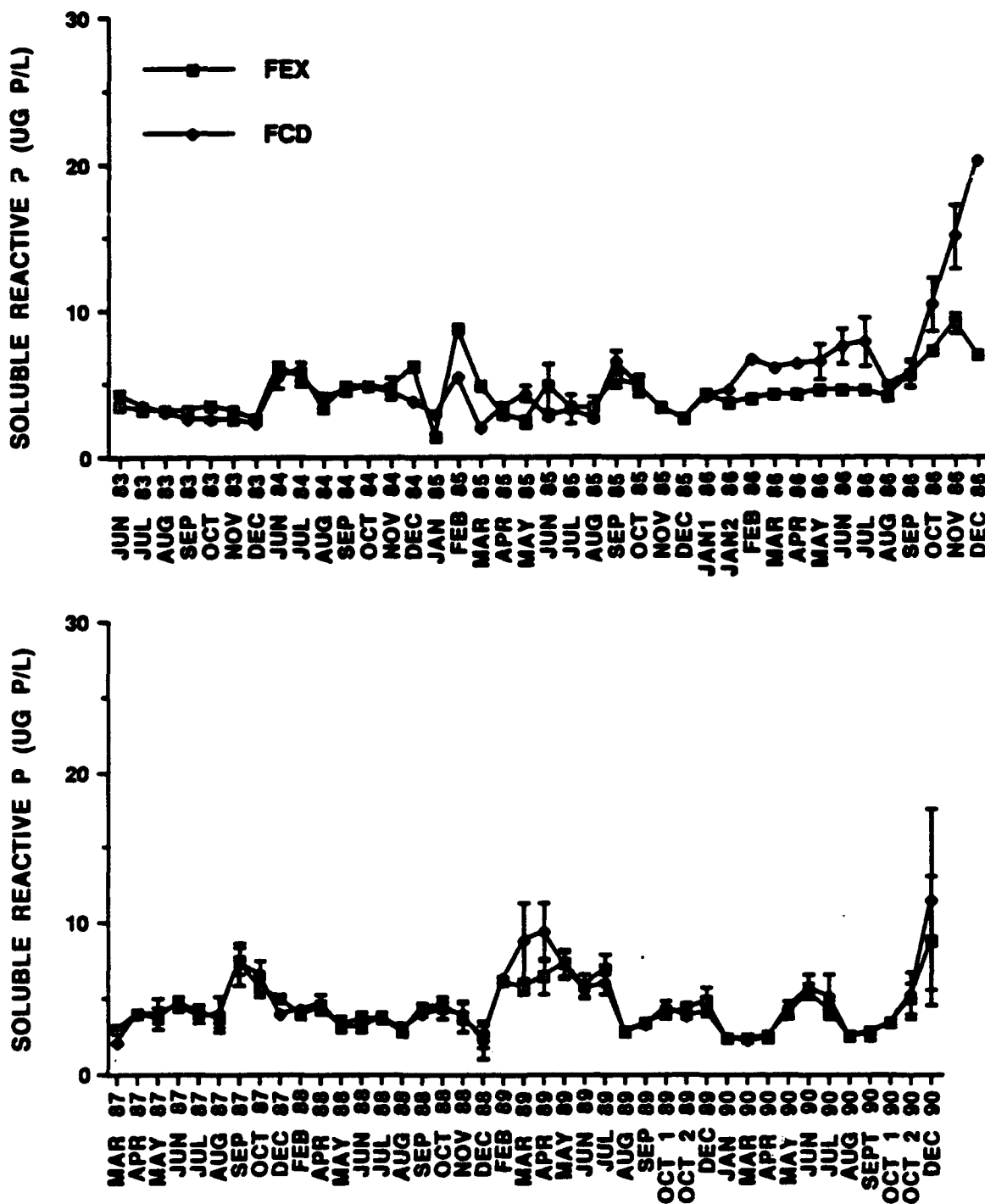


FIGURE 1.10 MEAN SOLUBLE REACTIVE PHOSPHORUS CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1990.

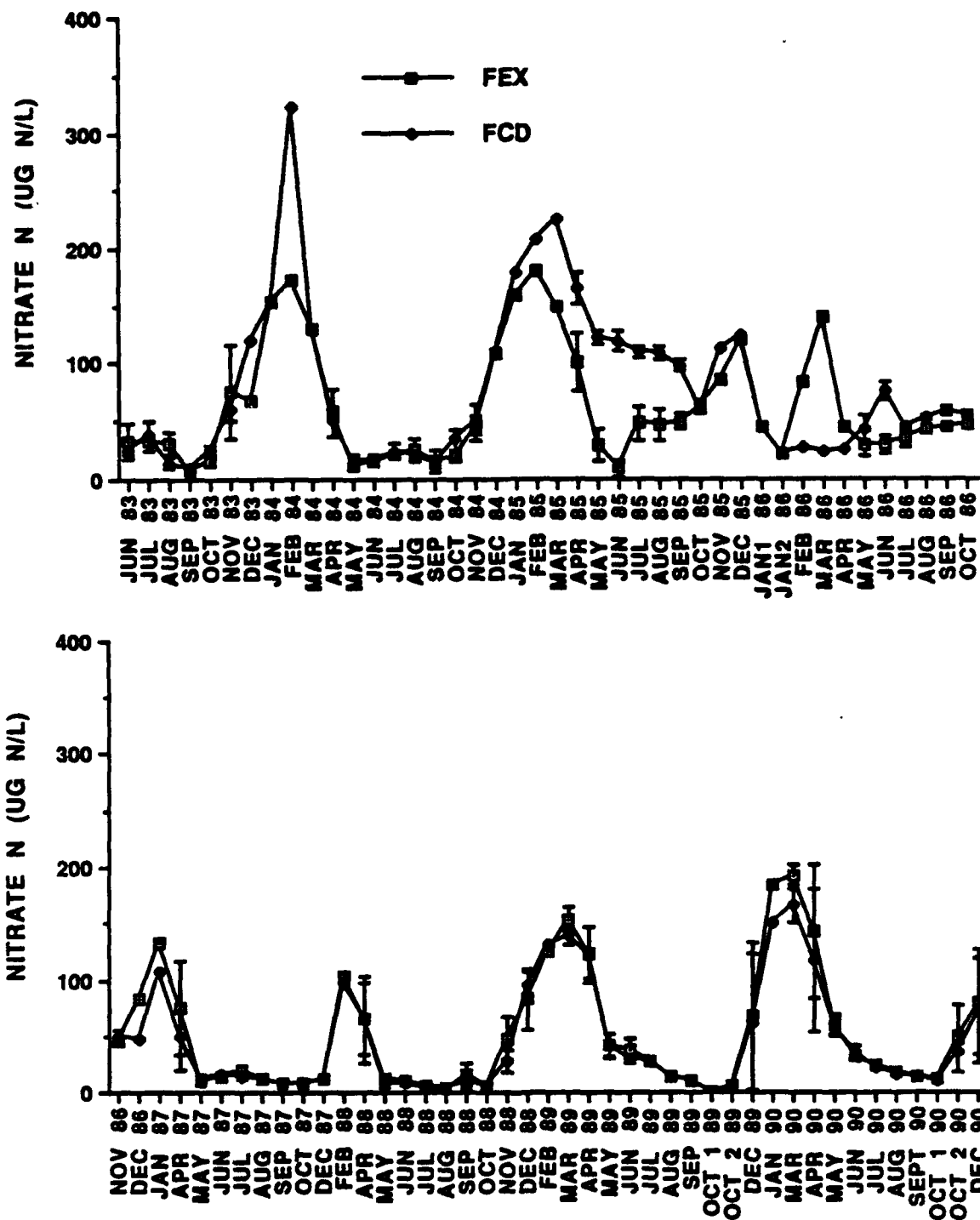


FIGURE 1.11 MEAN NITRATE-N CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1990.

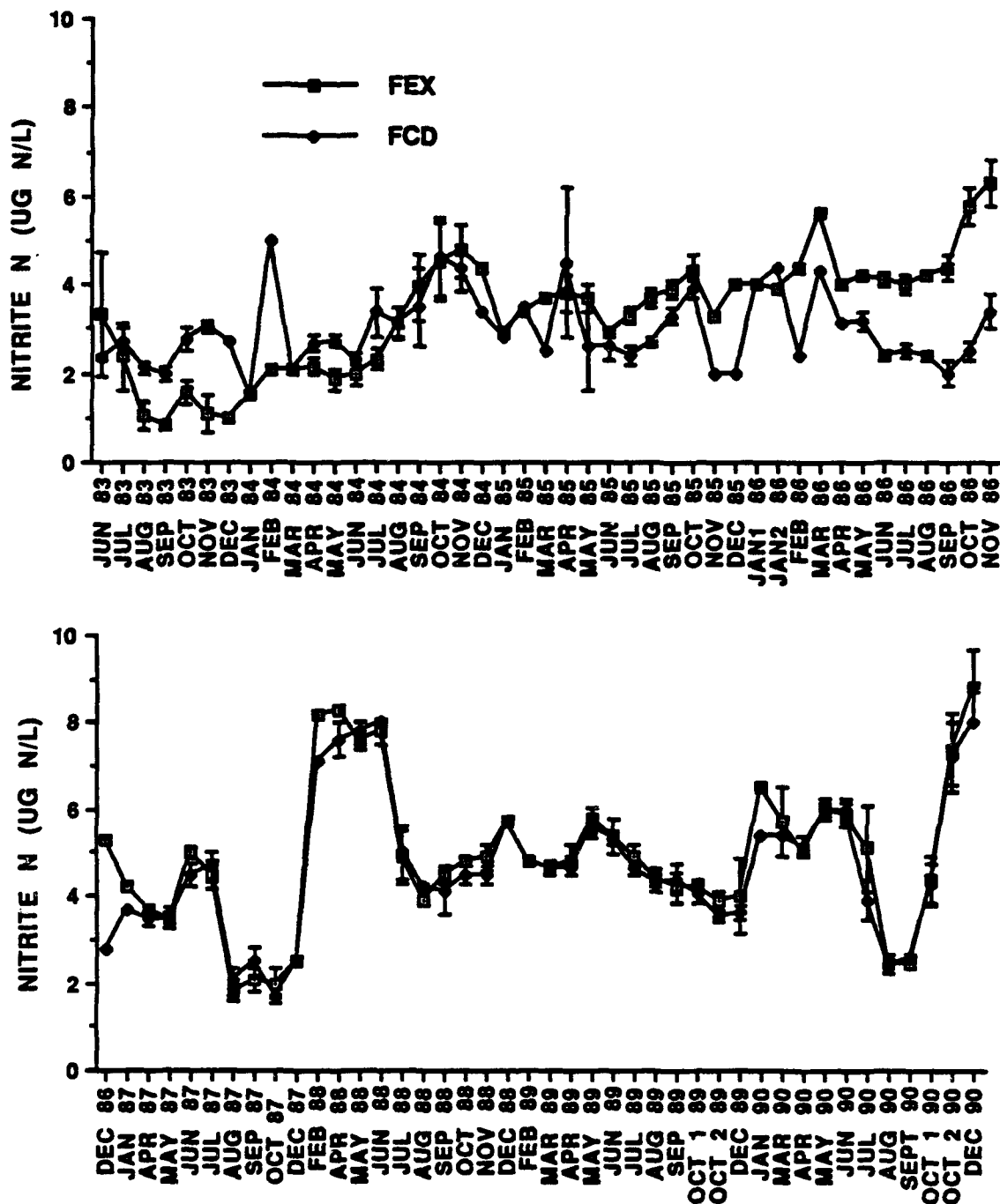


FIGURE 1.12 MEAN NITRITE-N CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1990.

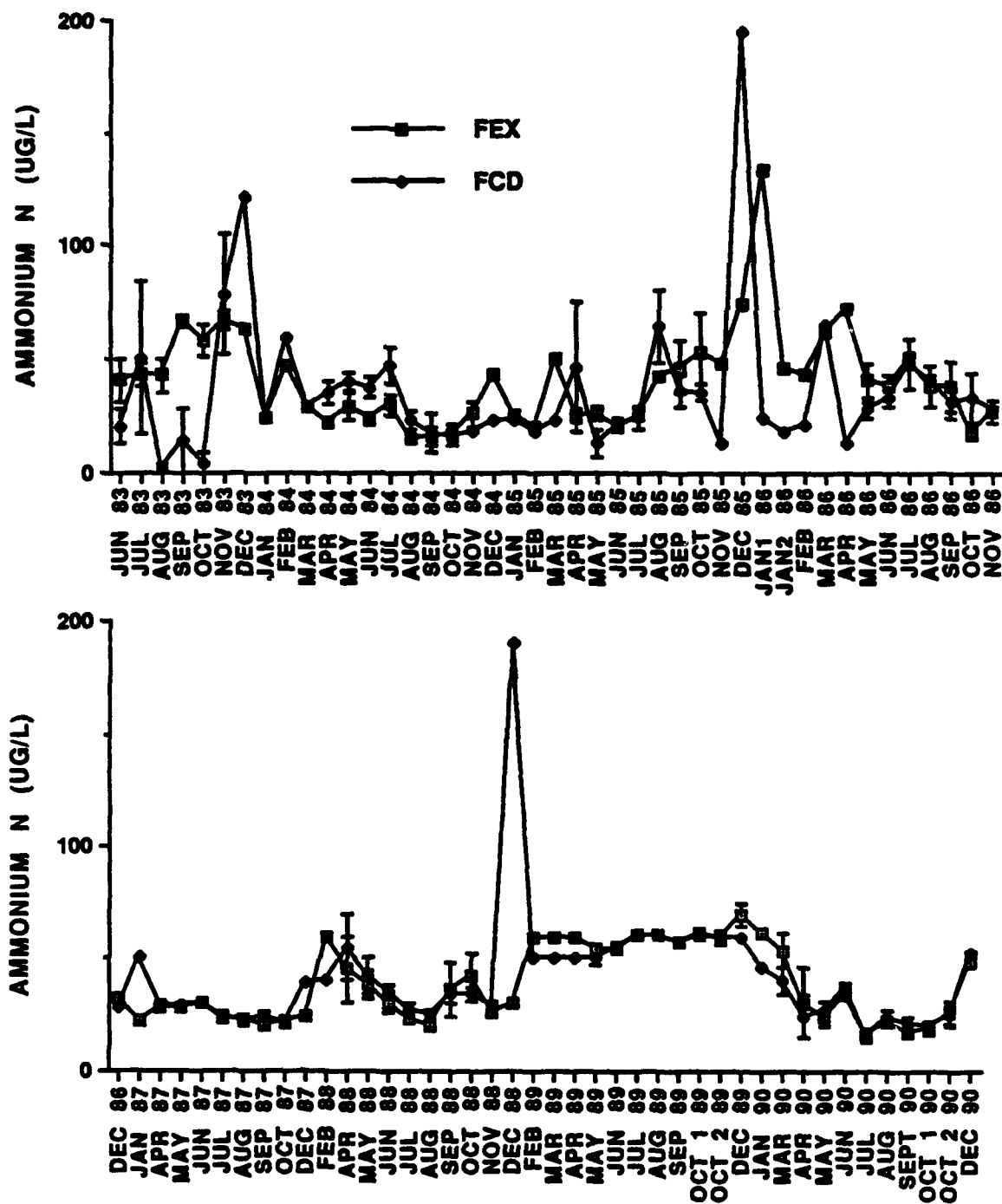


FIGURE 1.13 MEAN AMMONIUM CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1990.

Table 1.9 Ammonium ($\mu\text{g N/L}$), Nitrate-N ($\mu\text{g N/L}$) and Nitrite-N ($\mu\text{g N/L}$) for the Ford River for 1990. Values are Means \pm S.E., N in parentheses.

Date	Ammonium -N	Nitrate -N	Nitrite-N
Experimental Site (FEX)			
1/22/90	61.30 \pm 0.00 (1)	183.60 \pm 0.00 (1)	6.50 \pm 0.00 (1)
3/4/90	53.95 \pm 7.35 (2)	192.55 \pm 8.95 (2)	5.70 \pm 0.80 (2)
4/16/90	30.75 \pm 15.85 (2)	142.55 \pm 58.95 (2)	5.05 \pm 0.15 (2)
5/14/90	23.83 \pm 3.34 (9)	59.99 \pm 9.16 (8)	6.00 \pm 0.25 (9)
6/11/90	34.46 \pm 2.55 (9)	31.52 \pm 3.44 (8)	5.88 \pm 0.27 (9)
7/9/90	16.66 \pm 2.75 (9)	23.58 \pm 2.24 (9)	5.13 \pm 0.99 (9)
8/6/90	22.63 \pm 1.46 (8)	17.40 \pm 2.53 (8)	2.45 \pm 0.21 (8)
9/4/90	17.11 \pm 2.35 (7)	13.17 \pm 0.80 (8)	2.47 \pm 0.12 (7)
10/1/90	19.19 \pm 2.61 (9)	11.18 \pm 2.67 (9)	4.39 \pm 0.53 (9)
10/28/90	26.37 \pm 4.98 (9)	47.57 \pm 28.94 (9)	7.40 \pm 0.84 (9)
12/10/90	48.40 \pm 0.00 (2)	35.86 \pm 17.58 (2)	8.85 \pm 0.85 (2)
Control Site (FCD)			
1/22/90	46.60 \pm 0.00 (1)	150.40 \pm 0.00 (1)	5.40 \pm 0.00 (1)
3/4/90	40.50 \pm 6.10 (2)	165.60 \pm 15.20 (2)	5.40 \pm 0.00 (2)
4/16/90	24.65 \pm 9.75 (2)	116.75 \pm 64.05 (2)	5.15 \pm 0.25 (2)
5/14/90	26.82 \pm 4.12 (9)	58.14 \pm 9.56 (9)	6.00 \pm 0.16 (9)
6/11/90	36.98 \pm 2.83 (9)	35.47 \pm 5.34 (9)	5.99 \pm 0.29 (9)
7/9/90	15.91 \pm 2.43 (8)	21.80 \pm 1.77 (9)	3.92 \pm 0.44 (9)
8/6/90	24.14 \pm 2.63 (7)	15.56 \pm 1.87 (8)	2.43 \pm 0.16 (8)
9/4/90	20.84 \pm 3.21 (7)	12.94 \pm 0.69 (7)	2.60 \pm 0.10 (7)
10/1/90	19.80 \pm 2.48 (9)	9.59 \pm 1.99 (9)	4.29 \pm 0.49 (9)
10/28/90	24.87 \pm 4.50 (9)	35.86 \pm 17.58 (9)	7.21 \pm 0.80 (9)
12/10/90	52.30 \pm 1.30 (2)	71.90 \pm 46.10 (2)	8.00 \pm 0.00 (2)

analysis of land use changes in the watershed using aerial photographs and a geographic information system. Base maps have been prepared and overlays of land use changes are currently being prepared. Nitrate is the predominant form of inorganic nitrogen present in the Ford River. Thus, calculation of inorganic-N from the three components (Figs. 1.11, 1.12, 1.13) results in trends for inorganic-N very similar to those for nitrate-N (Fig. 1.14, Table 1.10). The patterns for inorganic-N and nitrate-N generally follow the pattern of mid-summer lows and winter highs described for nitrate for northern hardwood forests by Bormann and Likens (1979). These values are characteristic of values for streams in the eastern U. S. that are 50 to 90 % forested (Omernik 1977).

Inorganic-N values were not significantly different between the two sites in 1989-90 (Table 1.7). Concentrations of inorganic-N and nitrate-N at FEX were significantly correlated to concentrations at FCD (Table 1.7). In 1985-87, nitrate-N concentrations were significantly different between the two sites. This has not occurred since 1988 and did not occur in 1989-90 (Table 1.7), probably indicating a return to the patterns and levels exhibited prior to the 1985 clearcutting discussed above (Fig. 1.11). Ammonium-N and Nitrite-N also exhibited strong inter-site correlations in 1989-90 with no significant differences between sites (Tables 1.7, 1.8) (Note that there is an overall difference in nitrite from 1983-90 (Table 1.8) related primarily to large differences between the sites in 1986 (Fig. 1.12)). Nitrite levels have always been near limits of detection as is expected for unpolluted water.

Organic nitrogen at FEX was slightly but significantly different from organic-N at FCD prior to 1987 (Fig. 1.15), but these differences disappeared after 1987 (Fig. 1.15, Table 1.10). In 1989-90, there were no significant differences between FEX and FCD (Table 1.7), but the differences between sites prior to 1987 resulted in overall differences when all data were compared for 1983-1990 (Table 1.8). As was true for inorganic-N, total P, and SRP values, organic-N values were characteristic of streams draining areas of the eastern U. S. that are 50 to 90 % forested (Omernik 1977).

There were significant differences for silicate-Si between FEX and FCD in 1989-90 with FEX having slightly higher Si concentrations during 1990 (Tables 1.7, 1.11, Fig. 1.16). There had been no significant differences between the sites in previous years (Table 1.8), probably due to higher standard errors for each 28 day period in previous years (Fig. 1.16). Concentrations at FEX were

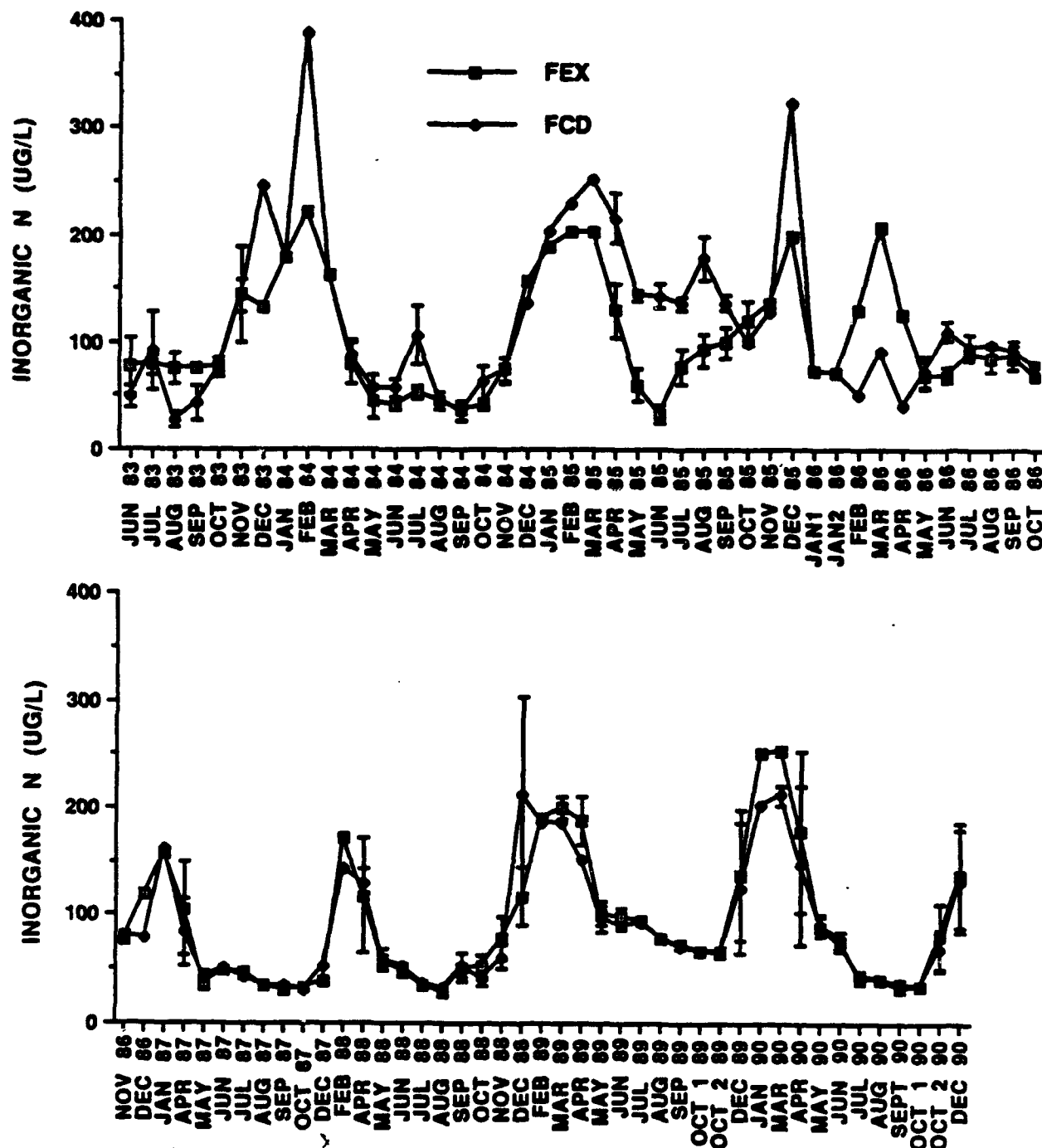


FIGURE 1.14 MEAN INORGANIC NITROGEN CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1990.

Table 1.10 Organic-N ($\mu\text{g N/L}$) and Inorganic-N ($\mu\text{g N/L}$) for the Ford River for 1990.
Values are Means \pm S. E., N in parentheses.

Date	Organic Nitrogen		Control (FCD)	Inorganic Nitrogen	
	Experimental (FEX)			Experimental (FEX)	Control (FCD)
1/22/90	402.75	(1)	*	251.40	(1) 202.40 (1)
3/4/90	122.19 \pm 280.56	(2)	*	252.20 \pm 0.80	(2) 211.50 \pm 9.10 (2)
4/16/90	*		31.42 \pm 9.29	(2) 178.35 \pm 74.65	(2) 146.55 \pm 74.05 (2)
5/14/90	274.65 \pm 75.53	(9)	417.69 \pm 134.77	(9) 89.92 \pm 9.90	(9) 90.97 \pm 9.73 (9)
6/11/90	565.10 \pm 98.90	(9)	804.56 \pm 153.31	(9) 71.86 \pm 4.22	(9) 78.43 \pm 6.08 (9)
7/9/90	844.41 \pm 140.09	(8)	733.00 \pm 170.45	(8) 43.71 \pm 5.36	(8) 40.88 \pm 3.97 (8)
8/6/90	343.01 \pm 31.09	(7)	291.29 \pm 25.98	(7) 40.17 \pm 1.95	(7) 40.16 \pm 2.47 (7)
9/4/90	321.15 \pm 21.64	(6)	336.42 \pm 39.97	(6) 32.76 \pm 2.42	(7) 36.39 \pm 3.10 (7)
10/1/90	493.69 \pm 39.82	(8)	455.11 \pm 42.46	(8) 34.76 \pm 3.87	(9) 33.68 \pm 3.47 (9)
10/28/90	422.94 \pm 25.53	(9)	313.40 \pm 54.09	(9) 81.33 \pm 30.58	(9) 67.93 \pm 19.23 (9)
12/10/90	273.15 \pm 148.07	(2)	95.06 \pm 16.85	(2) 137.40 \pm 47.70	(2) 132.20 \pm 47.40 (2)

* Concentration of organic-nitrogen too low to detect

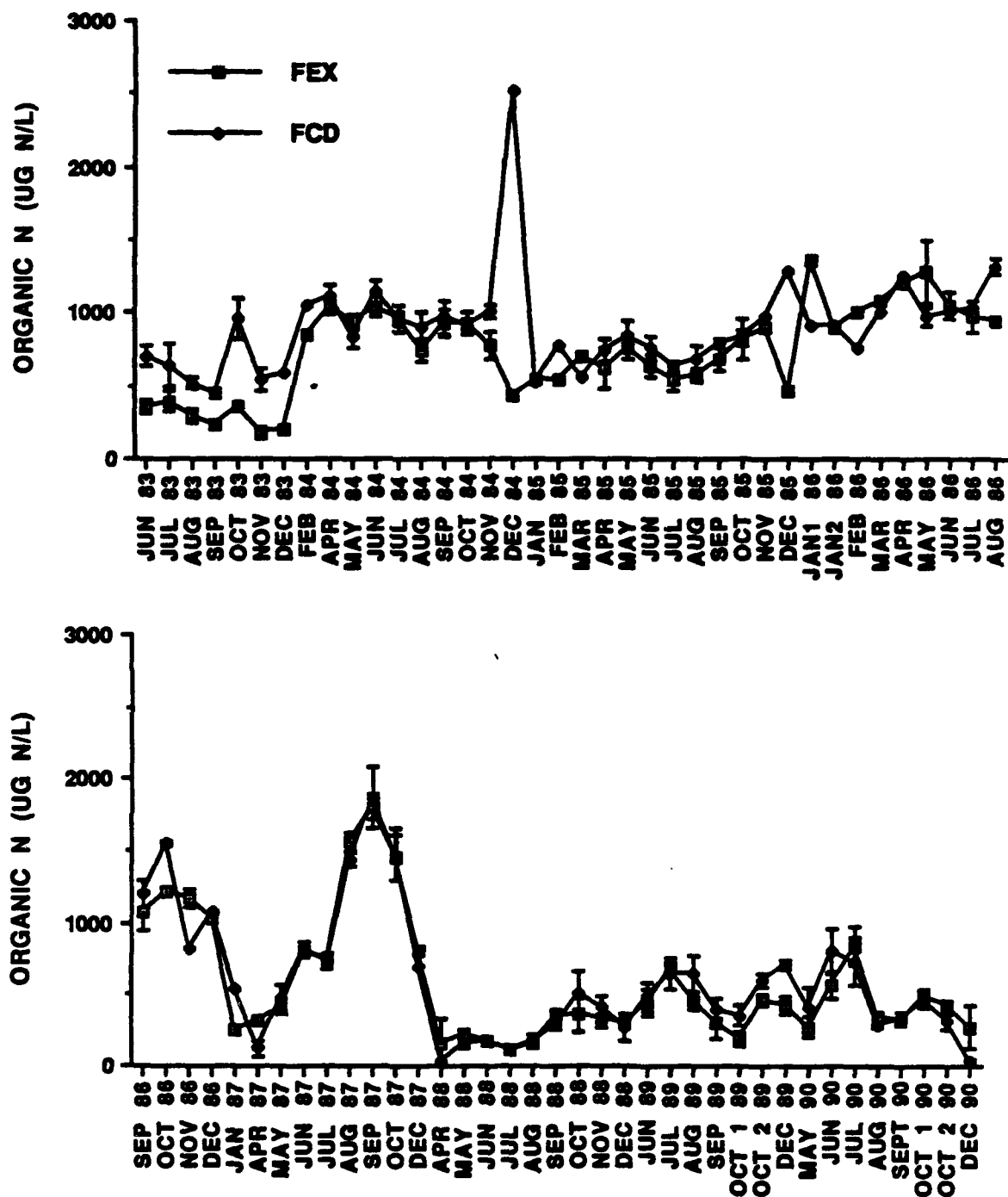


FIGURE 1.15 MEAN ORGANIC NITROGEN CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1990.

Table 1.11 Dissolved Silica (mg Si/L) and Chloride (mg Cl/L) for the Ford River for 1990.
Values are Means \pm S. E., N in Parentheses.

Date	Silica		Control (FCD)	Chloride				
	Experimental (FEX)			Experimental (FEX)	Control (FCD)			
1/22/90	10.40	(1)	10.10	(1)	3.90	(1)	3.40	(1)
3/4/90	10.30 ± 0.10	(2)	10.00 ± 0.10	(2)	4.00 ± 0.10	(2)	3.15 ± 0.25	(2)
4/16/90	8.05 ± 2.15	(2)	7.75 ± 2.15	(2)	4.80 ± 0.70	(2)	3.80 ± 0.90	(2)
5/14/90	5.06 ± 0.17	(9)	5.17 ± 0.14	(9)	4.67 ± 0.35	(8)	4.28 ± 0.21	(9)
6/11/90	5.31 ± 0.15	(8)	5.32 ± 0.08	(9)	4.37 ± 0.50	(7)	4.80 ± 0.56	(9)
7/9/90	6.80 ± 0.42	(9)	6.62 ± 0.32	(9)	3.59 ± 0.22	(8)	3.16 ± 0.32	(9)
8/6/90	7.66 ± 0.18	(8)	7.18 ± 0.12	(8)	3.49 ± 0.24	(8)	2.80 ± 0.10	(8)
9/4/90	8.36 ± 0.13	(7)	7.94 ± 0.12	(7)	2.97 ± 0.16	(8)	2.60 ± 0.10	(7)
10/1/90	8.58 ± 0.14	(9)	8.29 ± 0.17	(9)	4.56 ± 0.44	(9)	4.27 ± 0.55	(9)
10/28/90	8.18 ± 0.14	(9)	8.04 ± 0.12	(9)	5.04 ± 0.45	(9)	4.30 ± 0.34	(9)
12/10/90	8.35 ± 0.55	(2)	8.35 ± 0.45	(2)	4.10 ± 0.10	(2)	3.60 ± 0.00	(2)

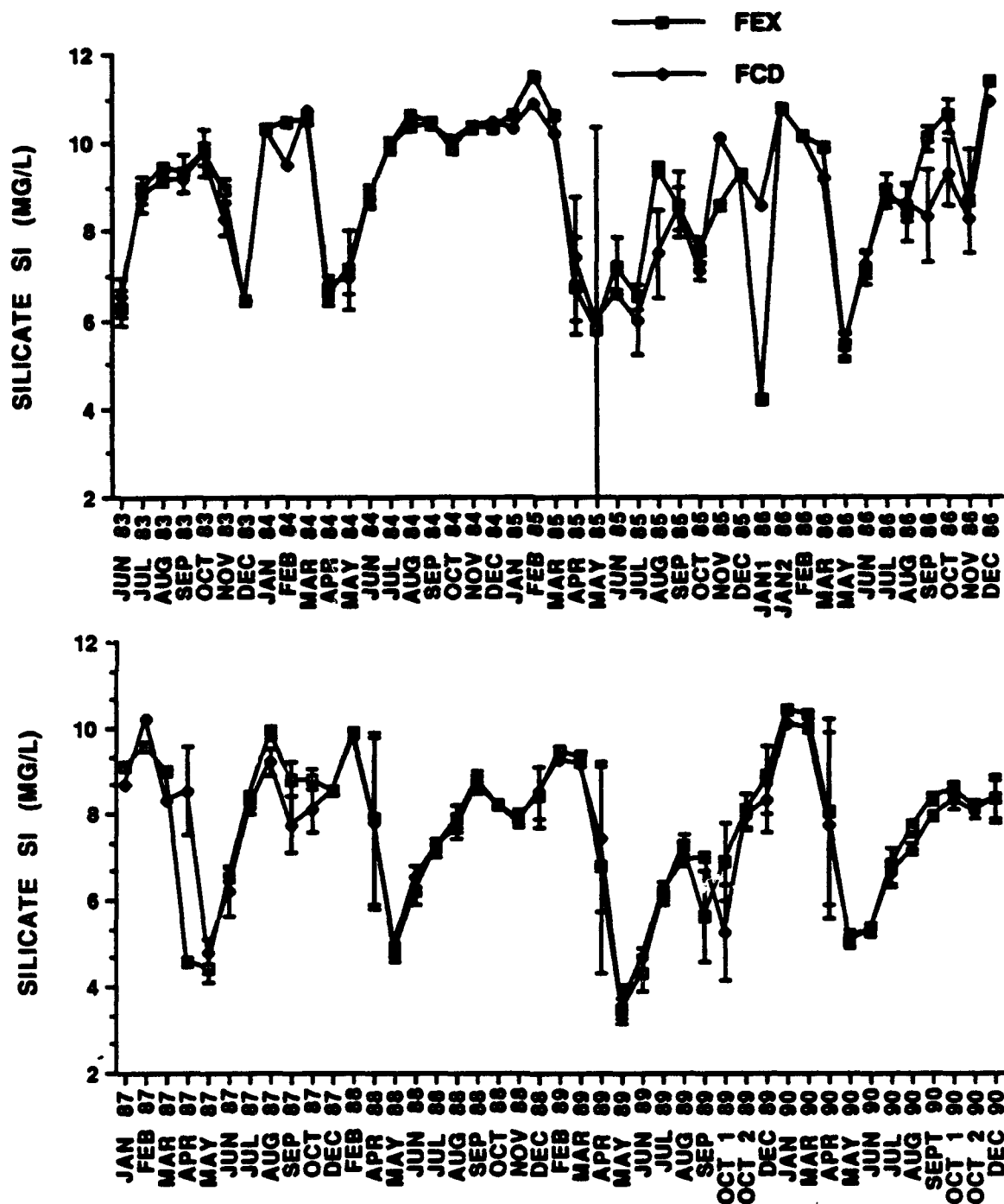


FIGURE 1.16 MEAN SILICATE CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1990.

significantly related to concentrations at FCD (Table 1.7) as had been the case in all previous years (Table 1.8). Overall, concentrations have remained relatively constant throughout most of each year studied at about 7 to 9 mg Si/L, except during periods of dilution that have occurred during high flows in April or May each year and during other periods of high discharge (Fig. 1.16, 1.5, 1.6).

Chloride at FEX was significantly different from chloride at FCD in 1989-90 (and in all previous years except 1987) (Table 1.7, 1.8, 1.11, Fig. 1.17). Values for the two sites were significantly correlated in 1989-90 (Table 1.7), as they had been in previous years. Concentrations of Cl have been slightly higher at the upstream site (FEX) for most years of the study than they have been at the downstream site (FCD) (Fig 1.17). This gradient may indicate some slight residual effects of chloride inputs from road salting near Channing, MI with dilution of these inputs in a downstream direction. However, concentrations even at the upstream (FEX) site are not much higher than one would expect from rainwater and are certainly much lower than any concentration known to cause problems for fish or other aquatic organisms (McKee and Wolf 1963).

C. Physical and Meteorological Parameters

The primary physical parameters monitored include air and water temperature, above and below water photosynthetically active radiation (PAR), and stream discharge. These data are automatically logged at 30 minute intervals from mid-April through the end of October. Almost no data are available from the winter months.

Solar radiation (PAR) was highly variable using the 30 minute interval data (Fig. 1.18). An integrating instrument would have provided more useful data but was not included in our original equipment list. Our 28 day summaries have been calculated as an average of the 30 minute PAR values for the period from 1000 to 1400 hours daily (Fig. 1.18). These data from the experimental site (FEX) are characteristic of data from both sites. Prior to 1990, we have a good record of PAR value at FEX, but a gap in above water PAR data at FCD does exist. The above water PAR data for FEX has been taken in an open area next to the river that is shaded only during early morning and late afternoon hours. FEX data are used for both sites in correlations of above water solar PAR with biological parameters such as algal productivity. Since data are collected in an open area, the only difference between sites should be related to differential cloudiness. These differences are not likely to be very large. This approach

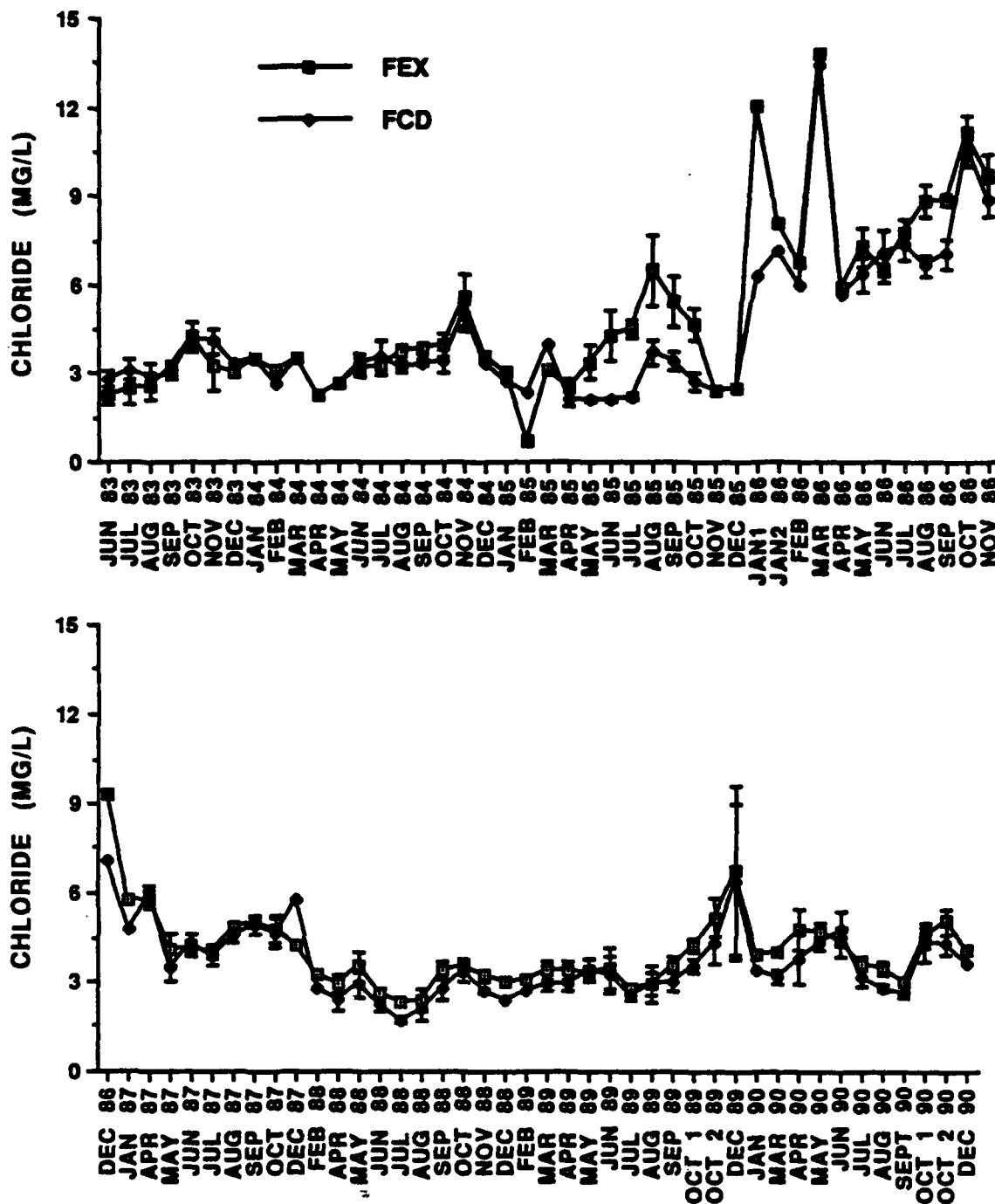


FIGURE 1.17 MEAN CHLORIDE CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1990.

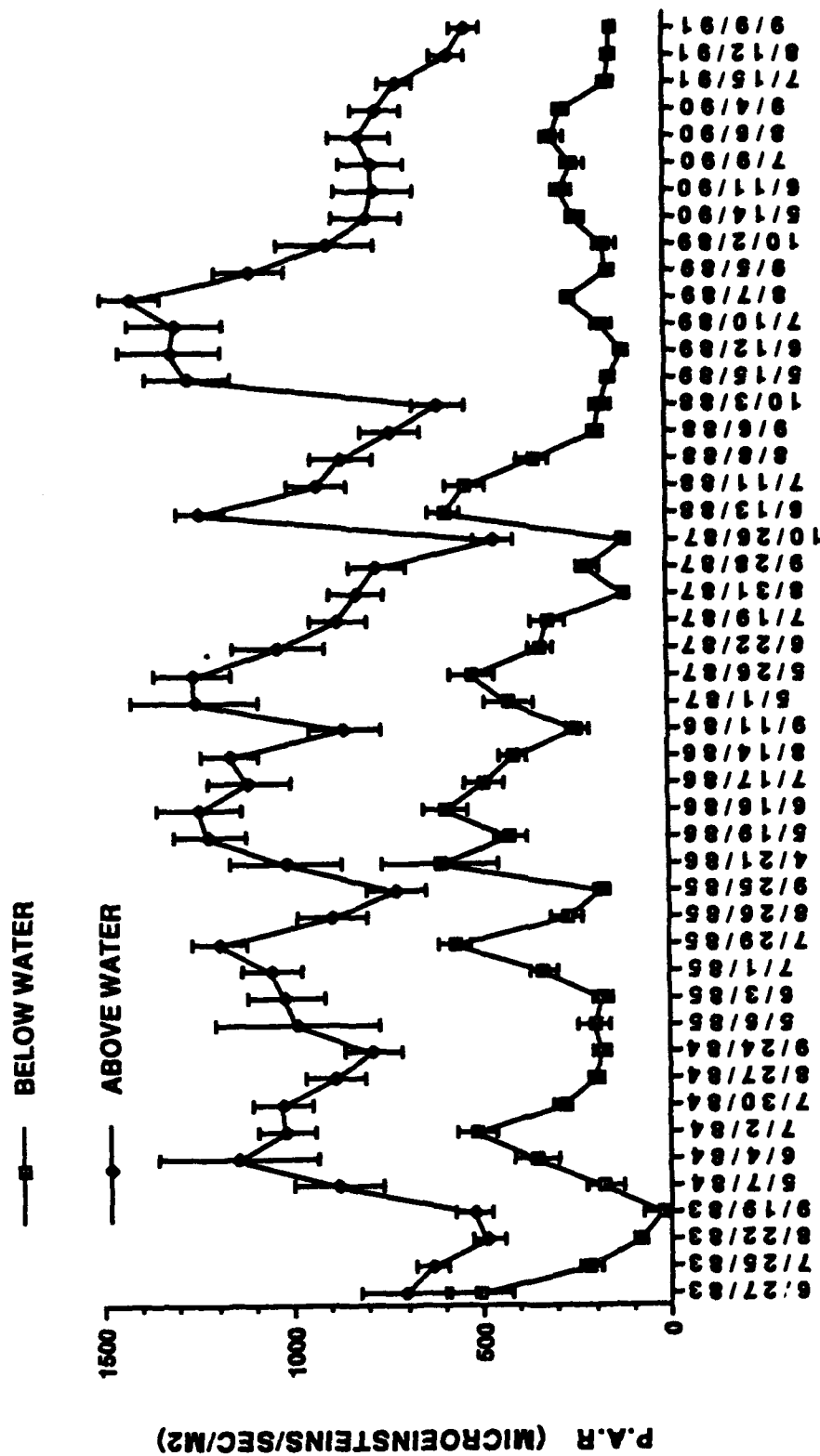


FIGURE 1.18 MEAN SOLAR RADIATION (+S.E.) BETWEEN 10:00 AND 14:00 FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) SITE, 1983-91. DATA FOR 1990 ABOVE HAVE BEEN CONVERTED BASED ON FCD DATA (SEE TEXT FOR DETAILS).

results in data for each 28 day period for open, unshaded areas of the river. While the diatom sites at both FEX and FCD are selected to be as open as possible, this approach overestimates actual PAR received. Underwater PAR is also monitored near the ambient monitoring station rather than directly at the level of the diatom collectors. In both instances, above and below water PAR can only serve as indices of actual PAR received at the river surface above the diatom collectors and underwater at the collectors rather than as actual measurements of PAR exposure received. No actual exposure data exists due to cable limitations (the cables that link the solar probes to the data pods are not long enough to obtain actual measurements). We have used FEX data in most years as an index of PAR exposure at both sites. In 1990, the FEX above water solar probe failed, and we used a conversion factor of 0.723 to convert FCD data to an estimate of what FEX data would have been (this conversion factor was developed in 1989 using data collected at the same time at both sites (Fig. 1.19)).

Air and water temperature have been monitored since 1983 and are available as needed. The water temperatures for 1991 are typical (Fig. 1.20, 1.21) of data over the growing season with temperatures rising rapidly from at or near zero under ice to 5 to 10° C before our monitoring stations are installed. Temperature continues to rise to mid-summer highs from mid-June through mid-August followed by cooling to about 12° C at the end of our reporting season. On subsequent monthly sampling trips from November through April, stream temperatures are at or near zero. The average temperature data for the 28 day exposure periods for the benthic algal sampling are summarized in Fig. 1.21. These data illustrate that average summer temperatures have been less than 20° C for every summer except 1983 and 1988 with 1988 attaining the highest average temperatures since the start of the study. The temperatures experienced in 1991 were lower than those of 1988 but still reflect the recent trend of low flows (Fig. 1.5) and high temperatures of the past few years.

Stream discharge data have already been presented for the 28 day benthic algal exposure periods (Fig. 1.5) and for mean daily values for 1991 (Fig. 1.6). However, the first three years of these data were calculated from actual discharge measurements taken with current meters once or twice per week. Initially, data were logged on Omnidatapods using modified Stevens Type F recorders. These data had to be converted to discharge using two regressions. The first related electrical output from the recorders to the datapods to actual water depth. The second related water depth to discharge using a standard

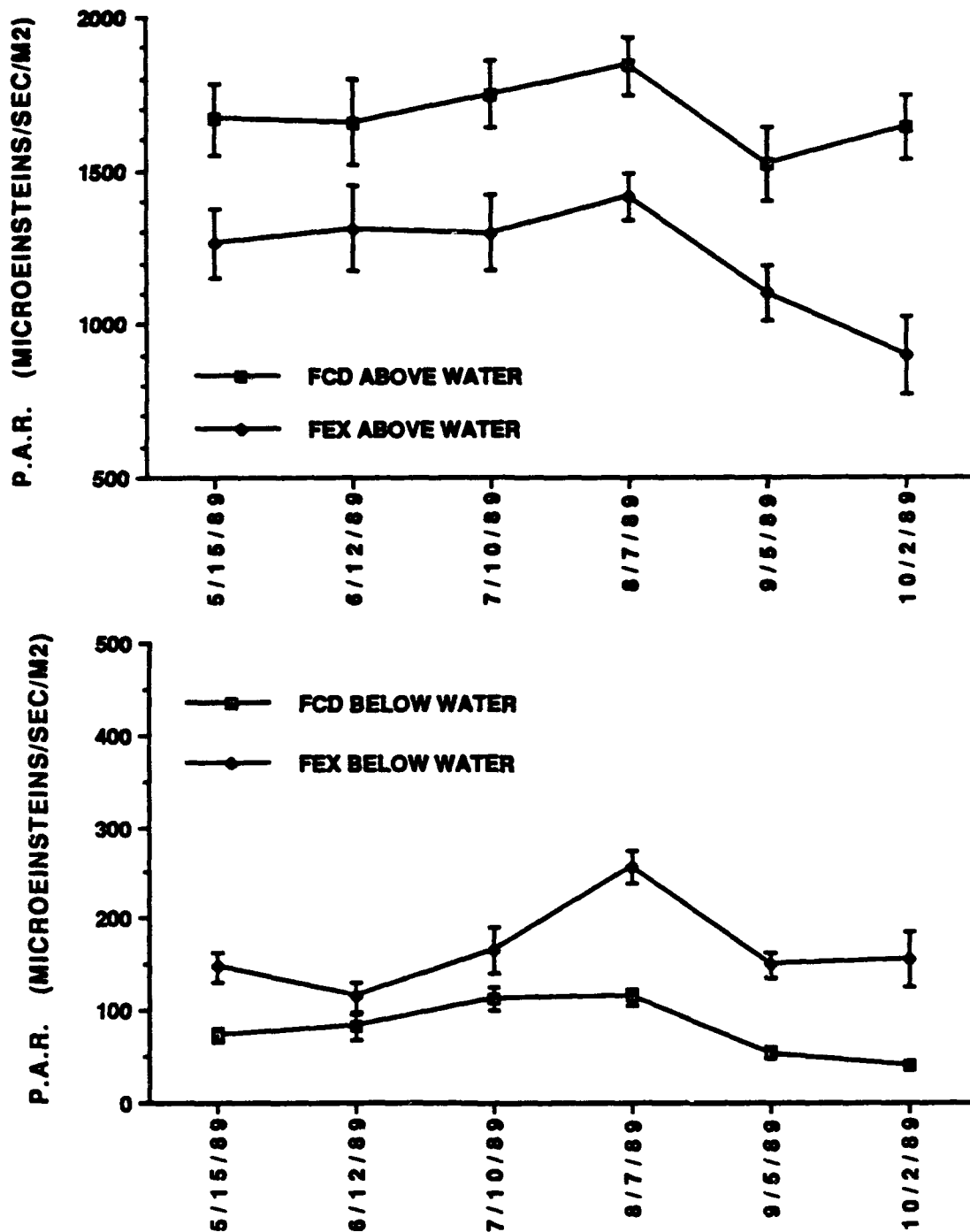


FIGURE 1.19 MEAN SOLAR RADIATION (+S.E.) BETWEEN 10:00 AND 14:00 FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1989.

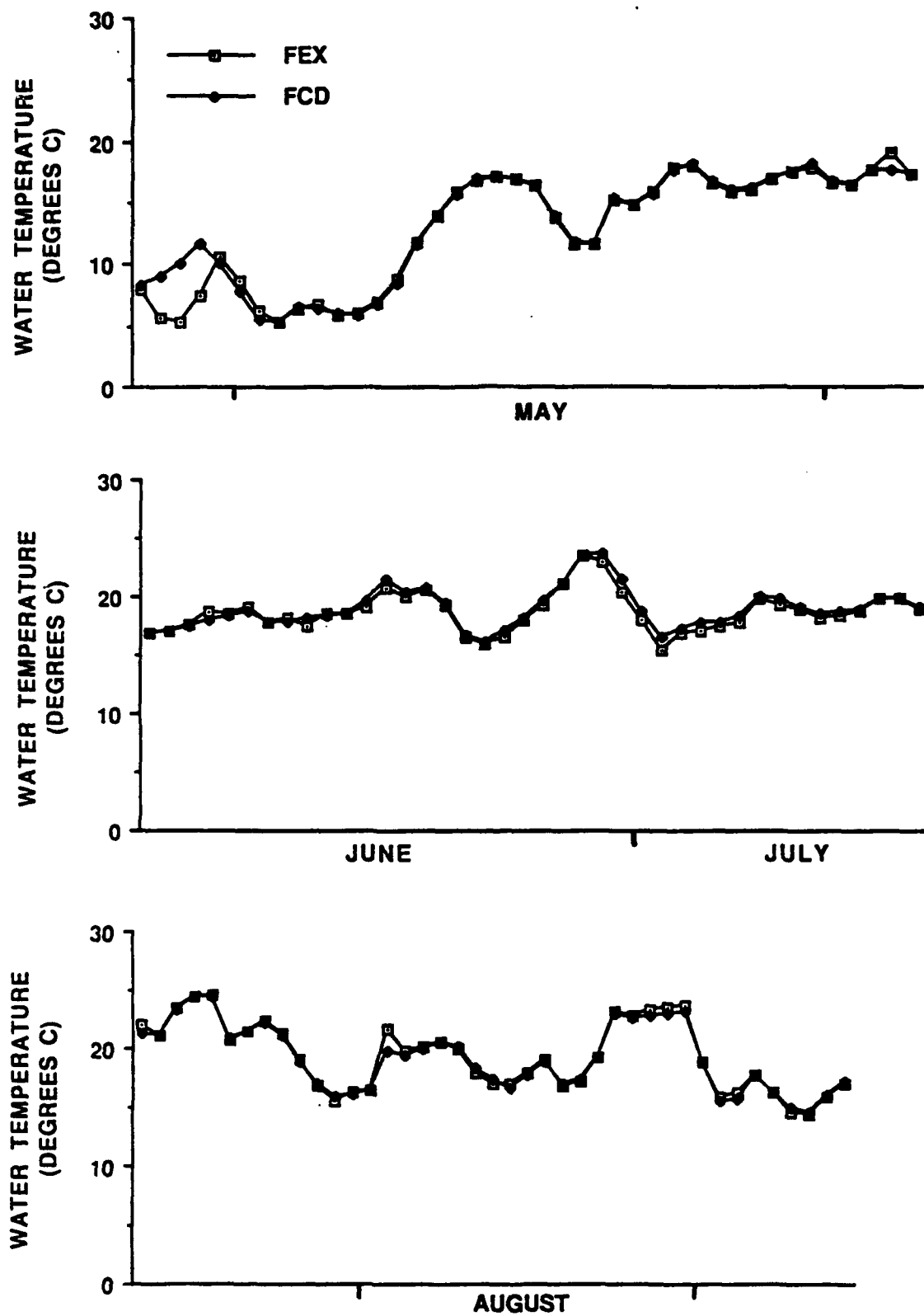


FIGURE 1.20 DAILY WATER TEMPERATURE MEANS FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES FOR 1991.

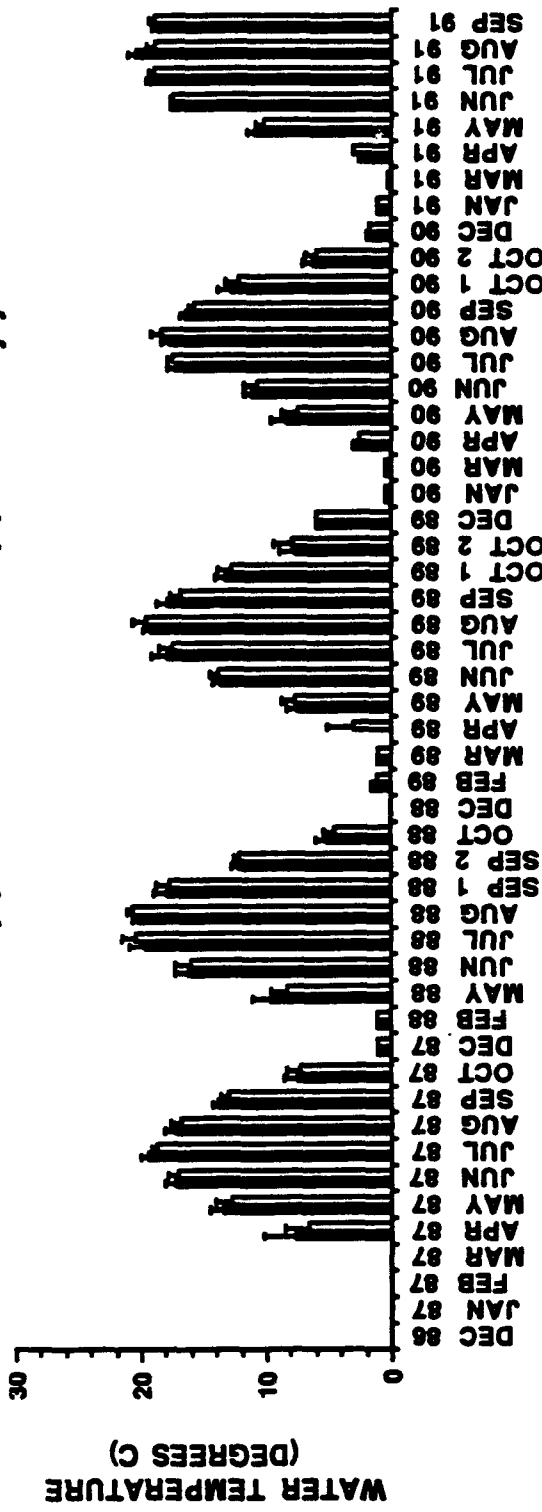
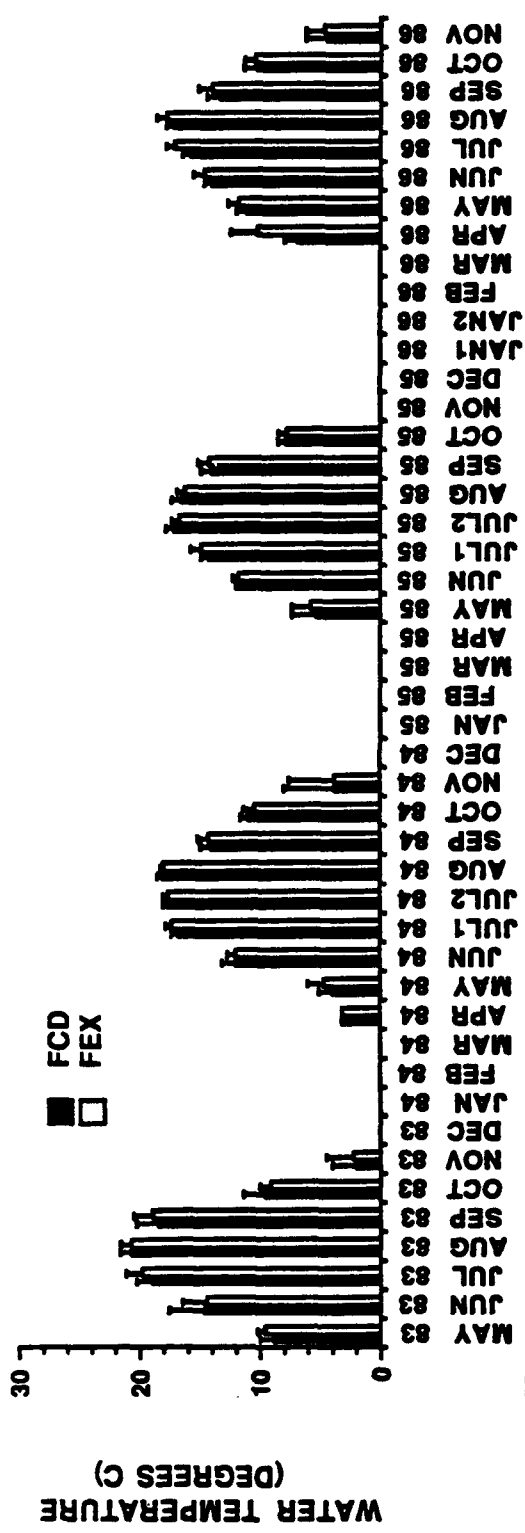


FIGURE 1.21 MEAN WATER TEMPERATURE (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1991.

depth-discharge regression. The first of these regressions changed any time the float line was set to a different position on the float wheel. Thus, retrieval and conversion of these data proved to be quite a chore. We have not yet completed this task. In 1986, this system was abandoned and the simple but effective strip chart recorder has been used since. Data on mean daily flows are currently available for all years since 1986.

Stream velocities were measured at all four periphyton sites from September, 1990 to September, 1991 (Figure 1.22). These data aided in the placement of periphyton samplers, so that all slides were exposed to similar flow regimes. Except for several high discharge dates during the year, water velocities were within an average of four cm/sec of one another at all four sites.

We have used data from the National Weather Service's nearest stations at Crystal Falls and/or Iron Mountain, MI to calculate the time that has lapsed between the time of removal from the river of each set of 28 day benthic algal samples and the time since the last major precipitation event. Our hypothesis that scour of algal biomass from the slides during large storms was having a major impact on some of the parameters measured for the periphyton task was not supported by the data. Since Crystal Falls/Iron Mountain data may not be precise for the Ford River, we have collected supplemental rainfall data for each site for the last several summers (Fig. 1.23) and will include these data in future regressions and correlations.

Exposure to ELF electromagnetic radiation is an important parameter used in covariate analyses. Data on 28 day cumulative earth electric field exposure (Figs. 1.24, 1.25) and cumulative magnetic flux exposure (Figs. 1.26, 1.27) were used in the covariate analyses reported in subsequent elements of this report.

D. Summary

Data for all chemical and physical parameters demonstrated that the experimental and control sites were very well matched. For the majority of the parameters, there were no significant differences between sites. When significant differences did occur between the chemical constituents, they usually involved a slight increase in a downstream direction. This trend of slight increase from the upstream site to the downstream site for hardness, alkalinity, nitrate, and organic nitrogen may be related to an expected accumulation of dissolved load in a downstream direction or to local land use differences between sites. Whatever the cause, the differences were small and probably

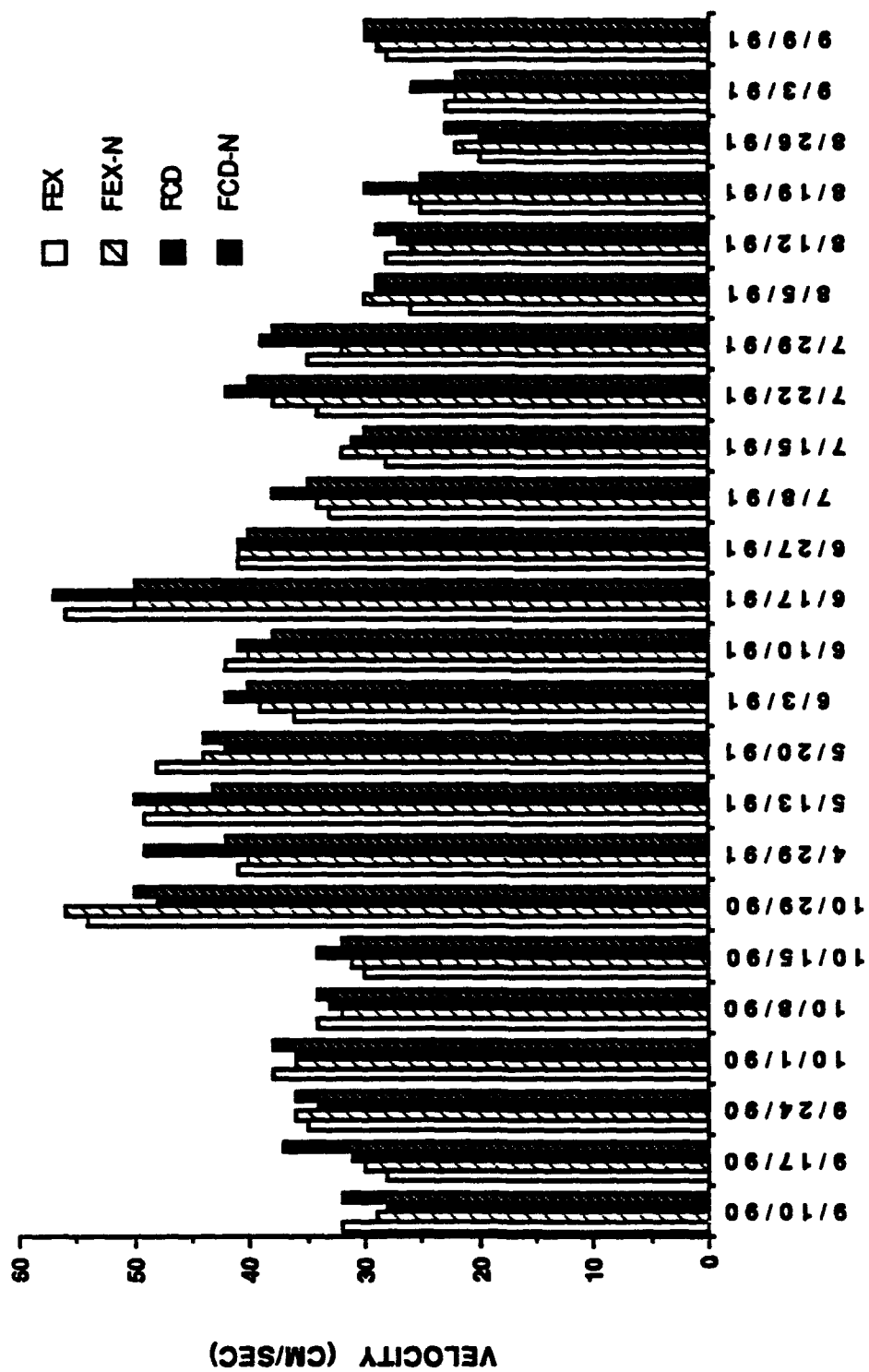


FIGURE 1.22 WATER VELOCITIES AT PERIPHYTON SAMPLERS FOR 1990-1991.

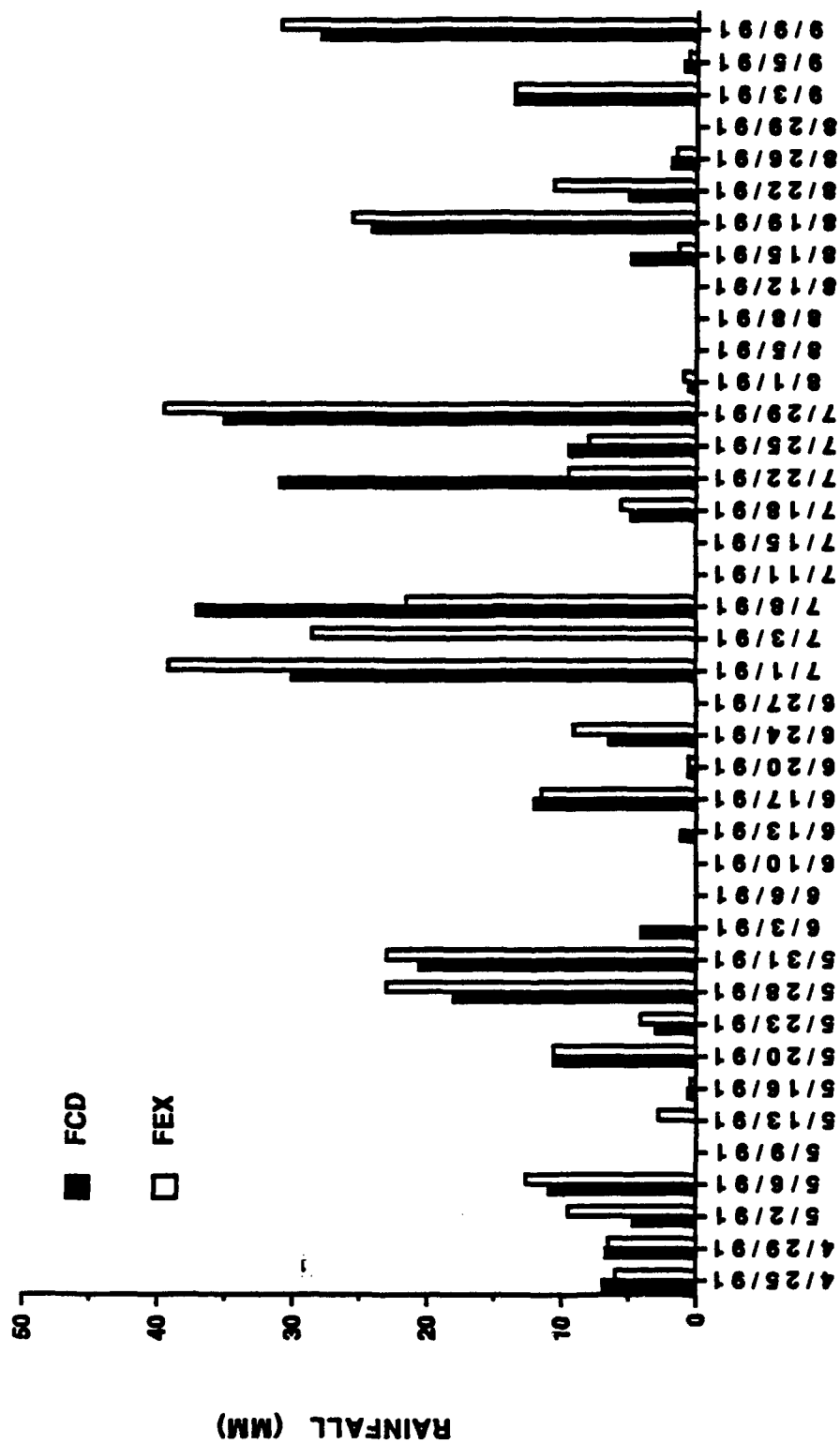


FIGURE 1.23 DAILY RAINFALL AMOUNTS FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES FOR 1991.

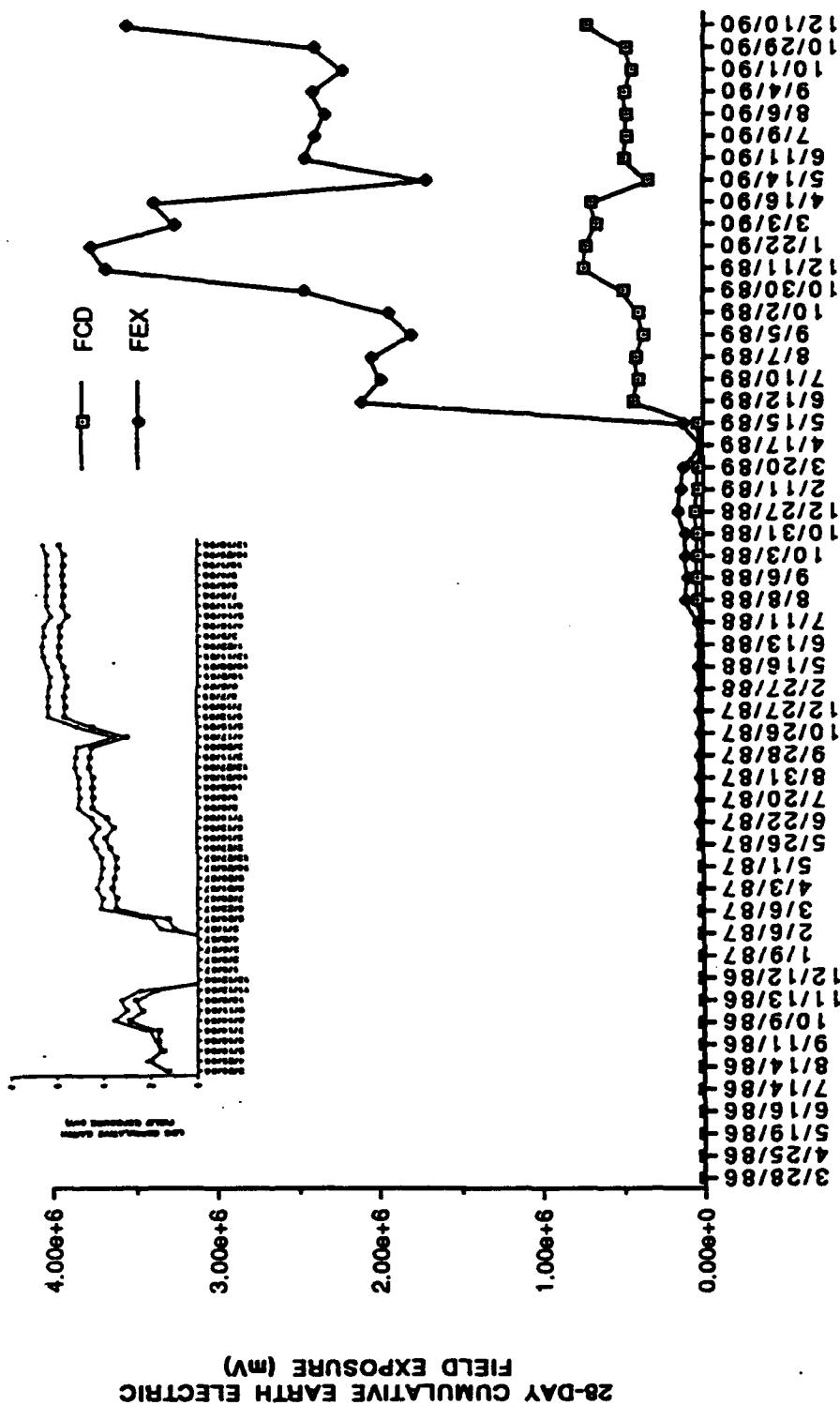
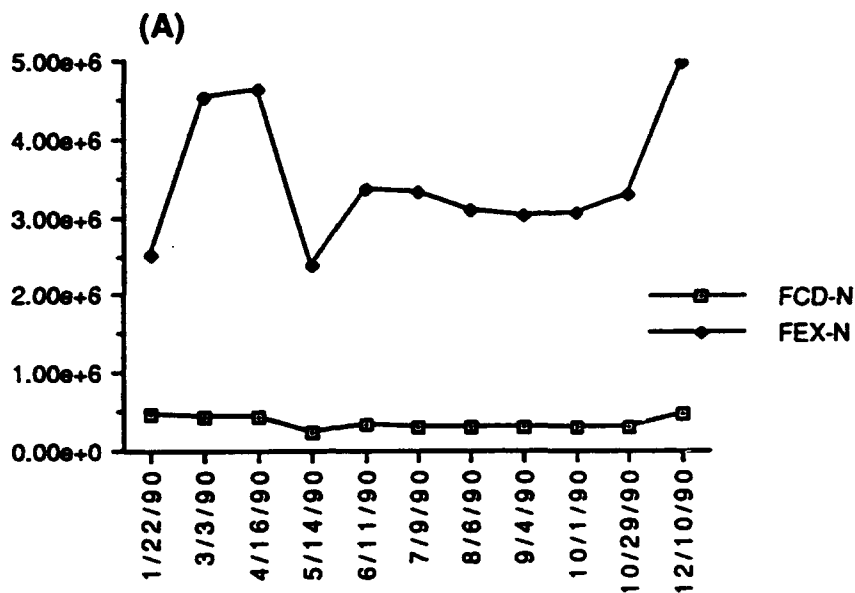


FIGURE 1.24 28-DAY CUMULATIVE EARTH ELECTRIC FIELD EXPOSURE DATA FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1990. THE INSET SHOWS THE LOG TRANSFORMATION OF THE EXPOSURE DATA.

28-DAY CUMULATIVE EARTH ELECTRIC
FIELD EXPOSURE (mV)



28-DAY LOG CUMULATIVE EARTH ELECTRIC
FIELD EXPOSURE (mV)

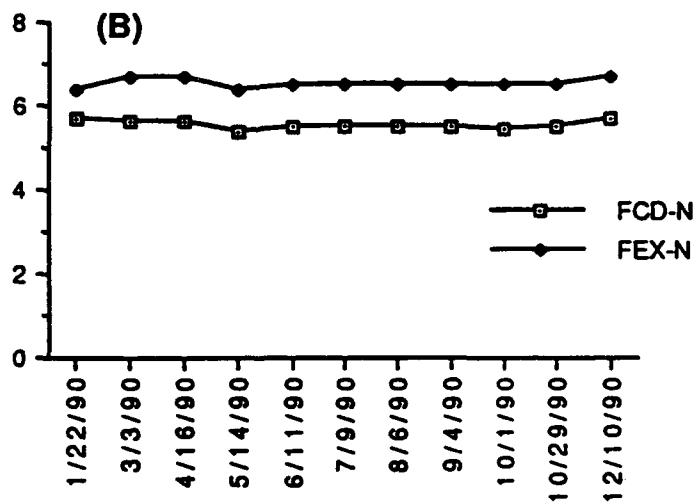


FIGURE 1.25 28-DAY CUMULATIVE EARTH ELECTRIC FIELD EXPOSURE DATA FOR FEX-N AND FCD-N SITES, 1990; (A) UNTRANSFORMED EXPOSURE DATA, (B) LOG TRANSFORMED EXPOSURE DATA.

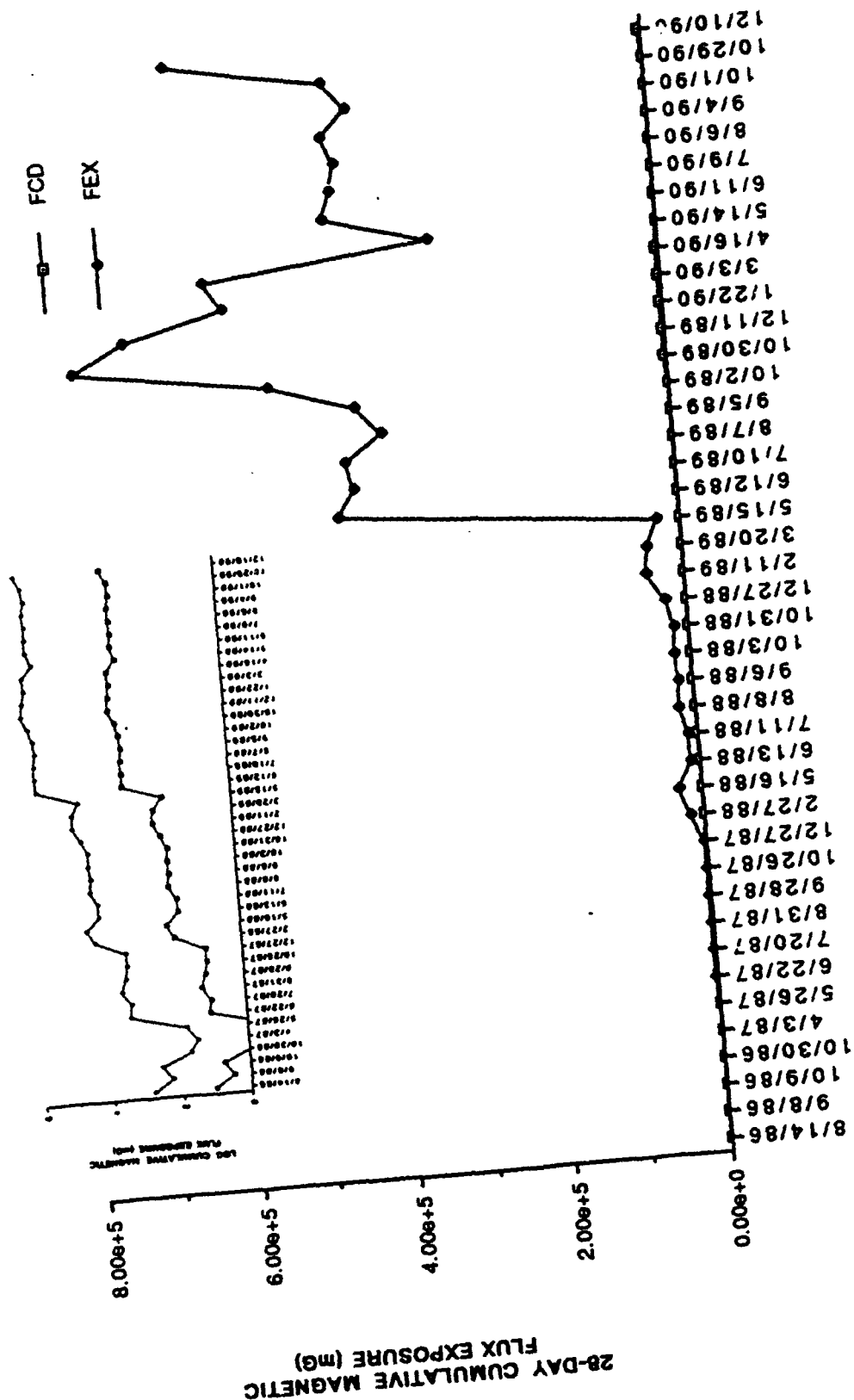


FIGURE 1.26 28-DAY CUMULATIVE MAGNETIC FLUX EXPOSURE DATA FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1990. THE INSET SHOWS THE LOG TRANSFORMATION OF THE EXPOSURE DATA.

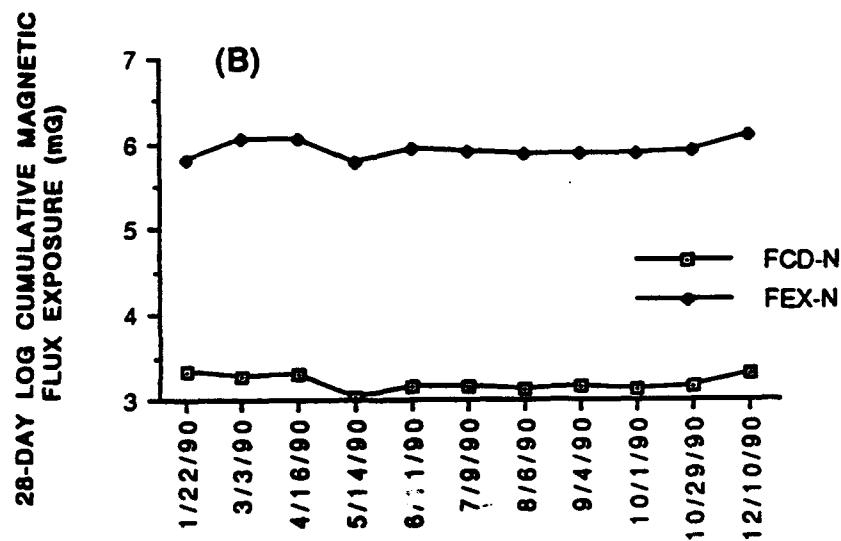
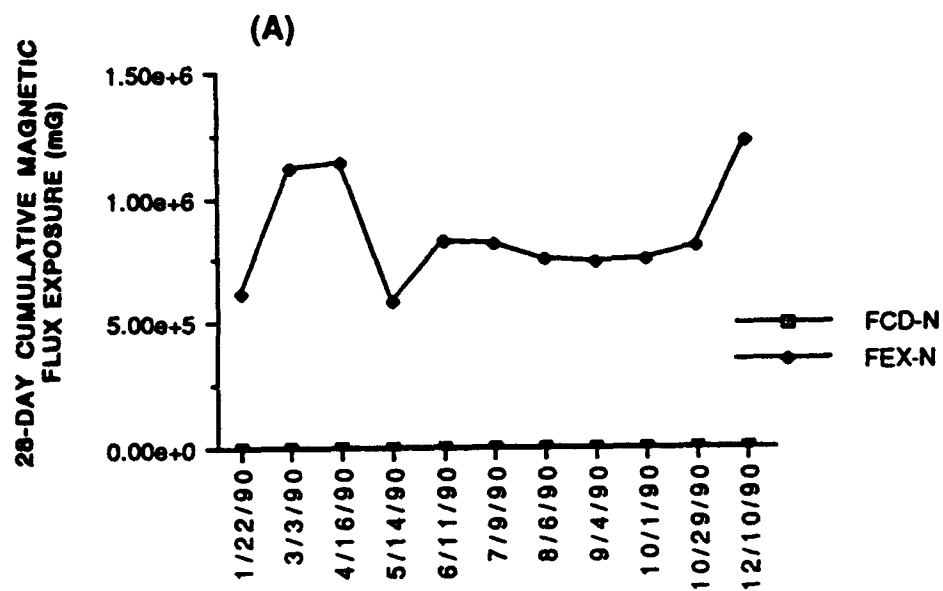


FIGURE 1.27 28-DAY CUMULATIVE MAGNETIC FLUX EXPOSURE DATA FOR FEX-N AND FCD-N SITES, 1990; (A) UNTRANSFORMED EXPOSURE DATA, (B) LOG TRANSFORMED EXPOSURE DATA.

would not lead to significant inter-site differences in productivity. We initiated experiments in 1987 to determine the impact of N and P inputs on the algal community. Both had to increase before significant changes in the algal community occurred. Clearly, no such shift in N and P has occurred.

Dissolved oxygen was only slightly below saturation at both sites but was slightly but significantly higher at FEX than it was at FCD. This is consistent with all previous years except 1988.

Chloride also was slightly but significantly higher at FEX than it was at FCD. This difference might reflect a slight amount of road salt influence from Highway M-95 at Channing, MI that is diluted in a downstream direction. This difference between the two sites did not occur in 1988. Even at FEX, chloride levels were only slightly higher than typical rainfall values. Thus, chloride should have little effect on the biota at either site.

Chemical and physical parameters for FEX and FCD demonstrated that these two sites were very similar with significant differences between sites showing up for less than one-third of the parameters monitored prior to 1990. The differences that did occur were slight and should have little impact on site productivity.

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Element 2 - Periphyton Studies.

Changes from workplan - The winter sampling schedule for the biological parameters was changed from monthly (28 days) to bimonthly sample collection in October 1987 resulting in three winter data sets. This routine was changed to once every 6 weeks for the winters of 1988-89, 1989-90, and 1990-91 to provide an additional winter data set. This additional data set proved necessary because of our current approach of analyzing the data on both an annual and summer/winter basis.

The chlorophyll a to phaeophytin a ratio was eliminated after the 1988-89 reporting year. It was reported in the past as an indicator of the physiological health of the algal community. The high variabilities encountered in this index made its usefulness in detection of ELF effects questionable.

Two new monitoring sites for this element were added in May, 1990 to increase the magnitude of the difference in ELF exposure between our control (FCD) and experimental (FEX) sites (See Fig. VII.1 for site locales). The ELF exposure rate at FEX under full antenna power is 61 mV/m resulting in an exposure that is only 5.0 times greater than the exposure rate of 12.3 mV/m at FCD. This difference is below the desired 10 fold difference in exposure rate called for at the beginning of this study. Two new sites (FCD-N and FEX-N, corresponding to IITRI designations 5C1-7 and 5T2-7 respectively) were added on May 15, 1990. The exposures of 7.9mV/m at FCD-N and 85mV/m at FEX-N result in a 10.8 fold difference in exposure between the two sites ($FEX-N/FCD-N = 10.8$). FCD-N is about 130 m downstream of FCD and FEX-N is about 40 m downstream of FEX (about 10 m downstream of the point where the antenna crosses the river). Note that our FEX-N site is within 5 m of FEX-Line, the new site used for insect studies. The insect FCD site has also been moved to within 10-15 m of our own FCD-N site.

In order to maintain continuity in the data base for making before and after comparisons, we continued to collect data from the original sites at FCD and FEX. We will continue to collect data from the original sites as well as from the two new sites until the end of the study. The use of the original sites and the new sites together will allow us to compare results along a gradient of exposures to ELF electromagnetic radiation ranging from background to an intermediate 5 fold increase in ELF exposure and to a high

of a 10.8 fold increase in ELF exposure within 10 m of the antenna crossing. This year we have presented all data collected (June 1990 to present) at each of the new sites and have analyzed the new data using paired t-tests. The additional person hours required to monitor all four sites were available because of the elimination of the study of periphyton-grazer interactions in Element 3.

Objectives

The objectives of the periphytic algal studies are:

- (1) to monitor any changes in chlorophyll a and organic matter accrual rates and standing crops as a result of ELF electromagnetic fields,
- (2) to determine algal cell volumes as an index of physiological stress in periphytic algal cells that might occur as a result of ELF electromagnetic fields.
- (3) to quantify any changes in species diversity, species composition, species evenness, and cell density that occur as a result of ELF electromagnetic fields, and,
- (4) to quantify any changes in primary productivity that might occur as a result of ELF electromagnetic fields.

Rationale

Structural Community Indices: Shifts in community composition of the attached algae provide a sensitive measure of changes in water quality (e. g. APHA 1980, Blum 1956, Patrick 1966, 1978). Introduction of pollutants often results in the reduction in numbers of individuals of sensitive algal species, increases in numbers of individuals of tolerant species, or the replacement of some species currently in the community with different species. These changes usually result in differences in species evenness (the number and distribution of individuals within the community) and richness (number of species within the community) leading to changes in species diversity (the information index that is a composite measure of richness and evenness) of the attached algal community. Since diatoms comprise more than 90 % of the attached algal community in the Ford River, our hypothesis is that shifts in the species composition of the attached diatom community will be a sensitive indicator of any effects of ELF electromagnetic

radiation on the algal community. Thus, we are using the Shannon-Wiener species diversity index, an evenness index, and measurements of species percent dominance for between site comparisons of attached diatom communities to detect subtle shifts in species composition that may occur as a result of ELF radiation. The diatom community which develops on exposed glass slides may consist of as many as 50-70 species on a single slide out of an estimated species pool for the Ford River of over 350 species. Changes in species abundance, species diversity, and species evenness of this community provide sensitive and statistically measurable parameters against which to measure seasonal variation, site variation, yearly variation and potential ELF effects.

In addition to studying the species composition of the attached diatoms, we are examining the relatively simple parameter of overall cell density. This directly determined density measure represents the numerical end product of species succession and abundance or dominance shifts by individual species in the attached algal community, and also includes the effects of physical environmental factors. The use of cell density, which is affected by both biological and physical factors, may reveal changes due to ELF effects. This single parameter is also a very important correlate with other estimates of production, such as chlorophyll *a*, or organic matter accrual. This labor intensive direct counting procedure is the yardstick against which other production estimates are often compared and should help separate potential ELF induced effects from other biological or physical influences.

Functional Community Indices: Measurement of the amounts of chlorophyll *a*, the primary photosynthetic pigment used by all algae, provides both quantitative and qualitative comparisons between sites. The quantity of chlorophyll *a* present can be directly measured through the intensity of its fluorescence and can be correlated with cell density and individual average cell volume to indicate the relative or qualitative physiological state of the algal community. Subtle effects of ELF electromagnetic fields on the photosynthetic pigment may result in a general physiological weakening of individual cells. This weakening may be observed as a decrease in the total quantity of chlorophyll *a* present, as well as a reduction the amount of oxygen generated through photosynthesis. The photosynthetic rate of the attached algae is monitored at both sites throughout the summer. This is a labor intensive task and is only feasible during the summer months when the entire field crew is at the research site.

This multiple approach of methodologies couples direct determinations of quantities of pigments present with direct measurements of oxygen levels produced by that pigment. Thus, these parameters allow statistical comparisons of production between sites throughout the year. Utilizing several different approaches allows us to continue analyses at times when we must rely on single approaches due to weather or labor constraints. For example, measuring chlorophyll a and organic matter accrual directly during winter provide estimates of production when the more detailed production studies of photosynthetic rates are not feasible.

In 1986 and 1987, we investigated a new statistical procedure defined by Stewart-Oaten *et al* (1986) to determine the suitability of this technique for analyses of the kinds of structural community indices that we were examining on the Ford River. The analysis, referred to as the BACI test, was demonstrated in the 1986 annual report to illustrate the technique and to see if it would be useful for significance testing on single species population abundances. In 1987, we continued our investigations into the use of the BACI analysis for functional indices, particularly chlorophyll a and AFDW-biomass. We used the method in 1988 to examine seasonal variations of each of the biological parameters from 1983 to 1988. Since 1989, we have continued the BACI analysis by adding additional data to the previous comparisons and have expanded the analysis to include: accrual rates, photosynthesis/respiration studies and abundances of rare algal species. This analysis has proved to be quite informative and is continued for 1991. In 1990, we introduced Randomized Intervention Analysis (RIA) as an additional means of analyzing biological and diatom abundance data. Based on the similar results obtained last year using both RIA and the BACI analysis, we have limited our current use of RIA to those biological parameters which failed to meet all assumptions required for the BACI analysis, or for significant inter-site comparisons found using the BACI analysis.

Our rationale has been to provide multiple data sets taken independently to be used in determinations of structural and functional indices. By incorporating several methodologies, we hope to detect and separate any "real" differences as a result of ELF electromagnetic radiation from either background variability or errors associated with a reliance on a single method of data collection or analysis.

Materials and Methods

Plexiglass slide racks were designed to hold 8 or 10 standard 7.6 x 2.5 cm glass slides in a vertical placement oriented facing the current in the river. These slide racks were fastened to bricks and placed in riffle habitats at the control (FCD, FCD-N) and experimental sites (FEX, FEX-N). Slides were removed after 14 days for chlorophyll *a* and AFDW-organic matter accrual rates and after 28 days (62 or 63 days during winter 1987 and 42 days during the winters of 1988, 1989 and 1990) for species composition and cell count determinations, chlorophyll *a*, and AFDW-organic matter standing crop determinations. Ten slides per site were used for each determination, except that this number was increased to 25 during the winters starting in 1987.

For species composition, cell counts, and cell volume determinations, 5 slides were removed on each sampling period from each habitat. Three slides were air dried and the other two were placed in a mixture of 6 parts water, 3 parts 95% ethanol and 1 part formalin (6:3:1 solution). These numbers were doubled during winter sampling starting in 1987. The air dried slides were later scraped in the lab with razor blades to remove the diatoms for further specimen cleaning and slide preparation. The slides preserved in the 6:3:1 solution will be used to determine species composition of non-diatom algae should this prove necessary. Preliminary comparisons have indicated that non-diatom algae comprise a minor component of the algal community in the Ford River. Thus, we have chosen to emphasize studies of diatoms.

Slides were prepared for specimen identification by cleaning the diatoms removed from the exposed glass slides in concentrated hydrogen peroxide (30%) followed by further oxidation of the cellular contents with the addition of small amounts of potassium dichromate (Van der Weff 1955). The cleaned diatoms were then rinsed with distilled water and settled in graduated cylinders. The final volume of concentrate containing the cleaned diatom frustules was then measured and 1 ml subsamples pipetted onto 22 mm² coverslips, until an adequate counting density was achieved. The coverslips were air dried and permanently mounted on glass slides using Hyrax medium.

Counting to determine diatom density calculations, and species determinations was done at 1250X magnification on a Zeiss microscope equipped with phase contrast illumination and an oil immersion 100X Neofluar phase objective with numerical aperture of 1.30. Transects were taken moving across the coverslip until approximately 500 frustules were counted. Estimates of diatom densities were then calculated from these quantitative samples via the equation:

(Valves Counted) (Area Coverslip) (Volume Concentrate)

Cells m^2 = 2 (Area Transect) (Volume Subsample) (Area Sampled)

Diatom species composition was recorded for each slide counted for determination of species richness, diversity (H') using the Shannon-Wiener formula (Southwood 1978; chosen for its more universal use and acceptance than other more obscure diversity indices), species evenness (J') (Pielou 1969, p.233), and dominance. Cell volume measurements were taken by measuring lengths, widths and depths and recording shapes of dominant diatoms for calculation of cell volume based on geometric formulae.

Analyses for chlorophyll *a* followed the fluorometric determination described in Method 1003C in Standard Methods (APHA 1980). All samples were analyzed within a month of collection. Initial analyses suggested no differences in these parameters whether or not the samples were ground first with a tissue homogenizer to facilitate cellular rupture. Therefore, this step was eliminated. Slides were collected, frozen for at least 24 hours to promote cell rupture, and then pigments extracted in 90% buffered acetone. Chlorophyll *a* was then determined following procedures outlined in Standard Methods (APHA 1980).

Organic matter biomass determinations were conducted following procedures 1003D for productivity estimates in Standard Methods (APHA 1980). While using the gain in ash-free dry weight per unit area as a measure of net bacterial and algal production (APHA 1980), we recognize that determining rates of primary production from a temporal series of biomass measurements results in minimal estimates of net production. The losses that may occur from excretion of organic compounds, respiration, mortality, decomposition, emigration, or grazing are certainly not included in determining this production estimate (Wetzel 1975). Likewise, accumulations of organic matter from physical processes such as flocculation or settling of dissolved and particulate organic matter are also possible (Lock et al. 1984). The accrual of organic matter biomass is a combination of processes involving dynamics of both colonization and production as well as physical processes. Results from our study of the colonization component on biomass accrual should increase the accuracy of these production estimates. Rather than list results as production, however, we will refer to them as organic matter accrual rates or AFDW-biomass accrual rates.

Statistical comparisons between sites emphasize the paired t-test, as recommended by one of our reviewers in past annual reports. Single year data for June, 1990

through September, 1991 and results for yearly and eight year paired t-tests on all parameters measured will be presented in this report. Additionally, emphasis has been placed on the analysis of biological parameters using the BACI and RIA techniques. Previous methods for analysis of "before" and "after" ELF effects as presented in earlier annual reports included the 3-way analysis of variance. The variables included a year, site and month effect for the selected parameter. While this analysis may prove to be the most statistically robust of several analyses available, they all may suffer from lack of true replication (Hulbert 1984). Because of such considerations and to expand our methods, we have analyzed our biological data according to the BACI method presented by Stewart-Oaten *et al* (1986) and the RIA method presented by Carpenter *et al* (1989).

The BACI design determines whether the differences between simultaneously collected samples of a given parameter at Impact (FEX) and Control (FCD) sites has changed significantly with antenna operation. The mean of the "before" differences between sites is compared to the mean of the "after" differences between sites by using an unpaired t-test. If the magnitude of the difference between the control and impact sites changes significantly ($p < 0.05$) after impact, there may be a significant antenna impact. The procedure assumes that the following criteria are met: (1) the measures of the parameters at any time are independent of the measures of those parameters at any other time, and (2) the differences between the control and impact sites of the "before" period are additive. According to Stewart-Oaten *et al* (1986), the independence of error assumption required by the BACI analysis may be considered to be "plausible if large, local, long-lasting random effects are unlikely". While our initial analysis of the data, as well as our sampling regime of 28-day independent measurements indicated that the assumption had been appropriately met, any possible serial correlations were checked for using the Durbin-Watson (1951) test. The second criterion was satisfied by transforming the data, if necessary (Steel and Torrie 1986). If regression of the differences versus the average at both sites for the raw or transformed data produced a slope that was not significantly different from zero (Tukey's Test for Additivity), the differences were additive. The differences for each period were then compared with an unpaired two-tailed t-test.

Using the BACI analysis, we examined seasonal variations of chlorophyll *a* and AFDW-biomass standing crop and production, cell volume, biovolume, cell density, species diversity, evenness, and diatom abundance. Seasons for this analysis consisted of a Summer (May to October) and a Winter (November to April) period, with all seasons prior

to Summer, 1986 representing the "before" period. The "transitional" period commenced July 22, 1986 at FEX with an average 4 amp ELF exposure for variable time periods during the day over 31 consecutive days. During 1987, the site at FEX received 15 amps for variable time periods during daylight hours from May 22 through August 31, 1987. The experimental site was exposed to 75 amps for variable time periods throughout most of 1988 and 150 amps from May 1, 1989 to October 7, 1989. Since October 7, 1989 the antenna has been operated full time and at full power. Our "after" period consisted of all data collected from October 1989 to present. Using the BACI design, we ran pooled comparisons on all the biological data except diatom abundance; i.e. all sampling dates from June, 1983 to April, 1986 as the "before" period and all dates from October, 1989 to September, 1991 as the "after" period. For each biological parameter, seasonal pooled comparisons were run; i.e. Summers (or Winters) 1983, 1984, and 1985 as the "before" period, and Summers (Winters) 1989, 1990, and 1991 as the "after" period. Additionally, individual seasons of the "before" period for each parameter were compared to "after" seasons to determine whether significant differences occurred. Transitional data will be analyzed as part of the final report after a satisfactory statistical protocol has been established.

Last year we included randomized intervention analysis (RIA) as a non-parametric alternative to the BACI technique (Carpenter et al 1989). The RIA design, like BACI, is based on replicated sampling over time, before and after a manipulation, at control (FCD) and experimental (FEX) sites. A mean difference between FCD and FEX was calculated from both the "before" and "after" data sets. The absolute value of the difference between these means represented the test statistic. Random permutations of the time series of inter-site differences provided an estimate of the distribution of the test statistic. In effect, we replaced BACI's unpaired t-test with a randomized error distribution taken from our own data sets. The proportion of randomly created differences between means that are greater than the observed difference between means, determined whether a significant change had occurred between sites after antenna operation. As with the BACI technique, a significant finding does not indicate that an antenna impact has taken place, but rather that some non-random change between sites has occurred.

By using a randomly created error distribution, the RIA design eliminated problems of non-normality and heterogeneous variances associated with the BACI technique. Carpenter et al (1989) does note that RIA may be affected by autocorrelations in the data. Our sampling regime of independent paired observations over time, along with the

Durbin-Watson test, reduces this autocorrelation problem. Another limitation of RIA, as demonstrated by Carpenter et al (1989), is the lack of test sensitivity with sample sizes of less than 40. Last year, we analyzed all the biological, gross primary production and diatom species abundance data using RIA. RIA comparisons made last year reflected results obtained using the BACI analysis. This year we used the parametric BACI analysis for data sets satisfying assumptions of independence and additivity. If the relationship between sites changed significantly over time, or if the independence, normality or additivity assumptions appeared to be questionable, then the non-parametric RIA was also used to examine the data. The same protocol of using total and pooled seasonal "before" and "after" data used with BACI was followed for RIA. Year-to-year comparisons were not made using RIA, due to small (2-17 observations) sample sizes.

RIA calculations were performed using the RIAPUB program obtained from Dr. Stephen R. Carpenter of the Center for Limnology, University of Wisconsin-Madison. The program, written in Fortran, is interactive in nature and is applicable for most studies of this type.

We also calculated the Minimum Detectable Differences (Zar, 1984 pg. 153) for each of our biological parameters. This tells us the magnitude of ELF induced change in any of these parameters that we will be able to identify statistically given the present level of variance and sample size for each parameter. In response to reviewer's comments last year, we have also added a power analysis of each of our biological parameters. A power curve was developed using the mean and standard errors associated with each summer and winter 1983-1990 data set at the control site. A power function provides information regarding the probability of correctly rejecting the null hypothesis of no significant difference at $p < 0.05$ level between the control and experimental sites for a set of assumed values of a biological parameter (Pfaffenberger and Patterson 1981). In order to standardize each power curve so comparisons could be made between parameters, power was calculated for specific percent changes in means for each biological parameter. Power was then plotted against the percent change in mean for each parameter. Ideally, the power of a function will rise very rapidly from zero as the percent change in observed mean departs from the true mean for a given biological parameter. Both the minimum detectable difference and power analysis will allow us to identify the parameters most likely to detect changes in the inter-site relationship over time.

In previous years we have used analysis of covariance (ANCOVA) with the ELF exposure data, presented in element 1, as the covariate to directly assess the effects of ELF exposure on the biological parameters. ANCOVA, as calculated in this study, provided a means of standardizing the values of each parameter at the two sites for the inter-site differences in ELF exposure, and permitted us to compare the standardized values between sites. This allowed us to determine if inter-site differences in any of our biological parameters are caused by ELF exposure. As an example, we compared the species diversity of the two sites (using a paired t-test) before the antenna was turned on and found no significant difference. The same comparison using data from the period after testing began on the antenna detected a significant difference between the sites. We used ANCOVA to test the hypothesis that this change in the inter-site relationship is caused by ELF exposures. To do this, ANCOVA was conducted on the after data set. The result of the ANCOVA was a significant inter-site difference in species diversity. Since the ANCOVA results did not differ from the results of the paired t-test on the same data set, we concluded that the change in the inter-site relationship indicated by the before and after paired t-tests is not due to the covariate, ELF exposure.

Upon further investigation of this procedure however, there is some doubt as to whether ELF exposure represents a valid covariate. Steel and Torrie (1960) states that ANCOVA was intended for use when the independent variable, or covariate, measures environmental effects not accounted for in the experimental design and is not influenced by treatments. In this study, ELF exposure is our treatment, thus possibly making ELF exposure an inappropriate covariate. Steel and Torrie (1960) then went on to say that if the covariate is influenced by the treatments, adjustments made by the ANCOVA calculations would remove part of the treatment effect. They urged that care be taken in the interpretation of the data. This year we ran the ANCOVA as in the previous years, using ELF exposure as a covariate, and reported the results in an earlier draft of this report. Based on reviewers' comments on the earlier draft, we have determined that our usage of ANCOVA with ELF exposure as a covariate is inappropriate, and have eliminated those analyses from this report. Next year, we plan to analyze our data using physical factors such as water temperature and discharge as covariates, instead of ELF exposure in the ANCOVA, as well as continuing the stepwise multiple regressions analysis.

While we increase the degree of statistical analyses performed, as well as the complexity of the analyses with each report as more data become available, a large inherent

variability still remains between our biological field samples collected at one point in time. For example, chlorophyll a determinations had coefficients of variation (C.V.'s) that averaged 32% in 84-85, 42% in 85-86, 37% in 86-87, 34% in 87-88, 38% in 1988-89, 30% in 89-90 and 45% in 90-91. AFDW-biomass had C.V.'s that averaged 40% in 84-85, 64% in 85-86, 45% in 86-87, 48% in 87-88, 36% in 88-89 and 89-90, and 45% in 90-91. C.V.'s for diatom cell density averaged 38% in 84-85, 39% in 85-86, 33% in 86-87, 45% in 87-88, 9% in 88-89, 18% in 89-90 and 11% in 90-91 (these lower C.V.'s since 1988 probably resulted from increasing the number of valves counted per slide from 300 to 500 as a means of effectively lowering the variation). All three important biological parameters showed average C.V.'s possibly too high to detect subtle differences due to ELF effects if comparisons are made at one point in time or for a single random sample period only. The individual C.V.'s of many of our monthly samples often fell below the 20% rejection level commonly used in benthic studies (Cummins 1975), in spite of the wide range in C.V. values observed over the course of a year. At times when the C.V.'s were low, statistical comparisons between sites provided a sample size sufficient to be 95% certain of detecting a 40% difference in means between the two sites at the 0.05 significance level (Sokal and Rohlf 1969). Coefficients of variation tended to be lower during low flow periods in summer and more variable during the higher waters seen in spring and fall periods. Thus, statistical comparisons in future reports will emphasize these time periods to be able to detect small differences between single time period comparisons. Our main efforts have been to use tests rigorous enough to detect differences using larger samples over time. We expect overall trends to be examined through the BACI and RIA techniques.

Derived measurements of species diversity or species evenness calculated from the field samples were characterized by much lower C.V.'s. C.V.'s for species diversity ranged from 1% to 27% for individual samples and averaged 10% in 85-86, 10% in 86-87, 6% in 87-88, 1% in 88-89, 2% in 89-90, and 4% in 90-91. For species evenness C.V.'s averaged 7% in 85-86, 6% in 86-87, 4% in 87-88, 5% in 88-89, 2% in 89-90, and 3.5% in 90-91. Again, the improvement in C.V.'s since 1988 reflects the increase in the number of valves counted per slide from 300 to 500 at that time. The derived measurements based on the actual density counts clearly fit the criterion of C.V.'s being lower than 20 % and offer sensitive parameters that can be used to detect ELF effects.

Results and Discussion

A. Colonization Patterns

In previous annual reports (AE-020, AE-031 and AE-045 for 1982-83, 1983-84, and 1984-85), we summarized data on colonization patterns for periphyton for the Ford River. These data demonstrated that for determining rates of productivity and organic matter accumulation, a 14 day period was best during the active growing season (mid-April to mid-September). This 14 day period coincided with rapid increases in chlorophyll *a*, phaeophytin *a*, and accrual of organic matter. Selecting this early period minimizes losses due to sloughing that increase as the periphyton community "matures" or approaches its maximum sustainable density on the slides (Burton and King 1983). This period of maximum daily increase in organic matter and chlorophyll *a* is often used as a measure of net production (APHA 1980; Burton and King 1983). Since the daily increases are less rapid during the cold weather, we used the 28 day period for estimates of daily productivity or accrual rate during the winter months from 1983 - 1986, a 56 day period for the winter of 1987 and a 42 day period for all winters since 1987, and the 14 day period from April through October for all summers.

After 14-21 days during exposure periods without major flood events, the periphyton community composition was shown to change slowly through time (Oemke and Burton 1986), and qualitatively approximated the mature community on natural substrates in the stream. Thus, standing crop estimates of chlorophyll *a*, organic matter, and all community composition parameters (cell density, species diversity, species evenness, and species dominance) are based on a 28 day exposure period throughout the year. All data from 1983-1991, excluding the winters since 1987, were based on this 28 day exposure period and sampling regime. During the winter of 1987-88, winter samples were taken at 56 day intervals. Since 1988-89, winter samples have been taken at 42 day intervals. As reported in the 1982-83 annual report (AE-20) and in Oemke and Burton (1986), differences between a slow flowing pool habitat, and the more rapidly flowing riffle habitat were either slight or insignificant as exposure length increased. Thus, all samples are presently collected from riffle areas only.

Data on these colonization dynamics were published in Hydrobiologia (Oemke and Burton 1986), and presented as an appendix in the annual report for 1986-87 (AE-071).

B. Patterns for Chlorophyll a

Chlorophyll a standing crop data for October, 1990 through September, 1991 followed annual patterns of summer peaks and winter lows (Fig. 2.1, Table 2.1). In general, values at the new FEX and FCD sites paralleled those of FEX and FCD, respectively (Table 2.1). Annual patterns have indicated that chlorophyll a peaks during the summer months of July or August, although in 1989 and 1990 the highest chlorophyll a standing crops have occurred in May. In 1991, the highest chlorophyll a standing crop at FCD and FCD-N occurred in May, but at FEX and FEX-N occurred later in the summer and remained high through September (Table 2.1). The chlorophyll a levels over the last few summers are higher than those recorded prior to 1987 and are probably associated with the higher temperatures and lower flows experienced over the past few years. Most measures of algal standing crop (density, chlorophyll a, AFDW-organic matter accrual), as well as species composition appear to have increased as a consequence of the very dry weather in May and early summer for the past five years (with the exception of June 1989). Another consistent pattern for chlorophyll a has been that standing crop has been low in winter (Fig. 2.1). As reported earlier, winter 1986-87 was characterized as being moderate in severity, with substantially warmer temperatures, resulting in less ice cover for the Ford River. The levels of pigment observed for 1986-87 winter were much greater than those observed in any other winter (Fig. 2.1).

The period of highest variability has generally been the periods from late March through June. This period sometimes contains secondary peaks in standing crop production, e.g. April 1984, May 1986, 1989, 1990 and 1991 (Fig. 2.1). This secondary peak seems to be associated with dry spring seasons with low flows and relatively warm temperatures following snow melt runoff events.

Paired t-tests and correlations of biological parameters from June, 1990 to September, 1991 were used to compare chlorophyll a levels for FEX vs FCD, FEX vs FEX-N, FCD vs FCD-N, FEX-N vs FCD-N (Tables 2.2-2.5) and the entire data set from 1983-1991 (Table 2.6). Results of the paired t-test indicate no significant difference in chlorophyll a levels except for the FEX-N vs FCD-N comparison (Table 2.5), the most extreme comparison of ELF exposure. All site comparisons were shown to be significantly correlated.

We have also computed the minimum detectable differences for each of our biological parameters (Table 2.7). This was done according to the method provided in Zar

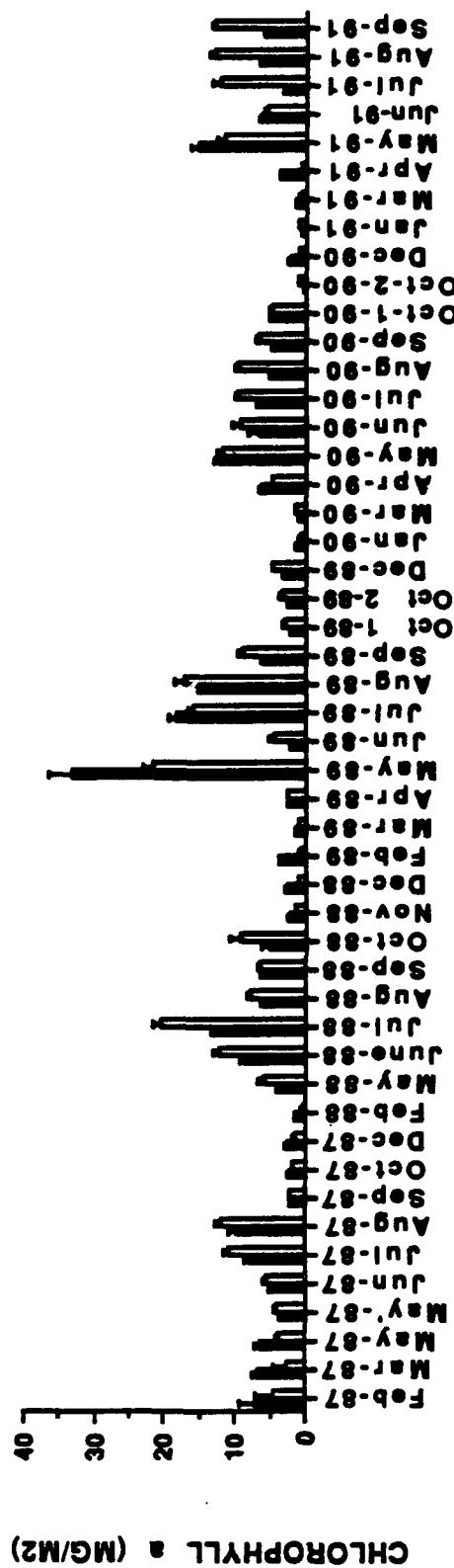
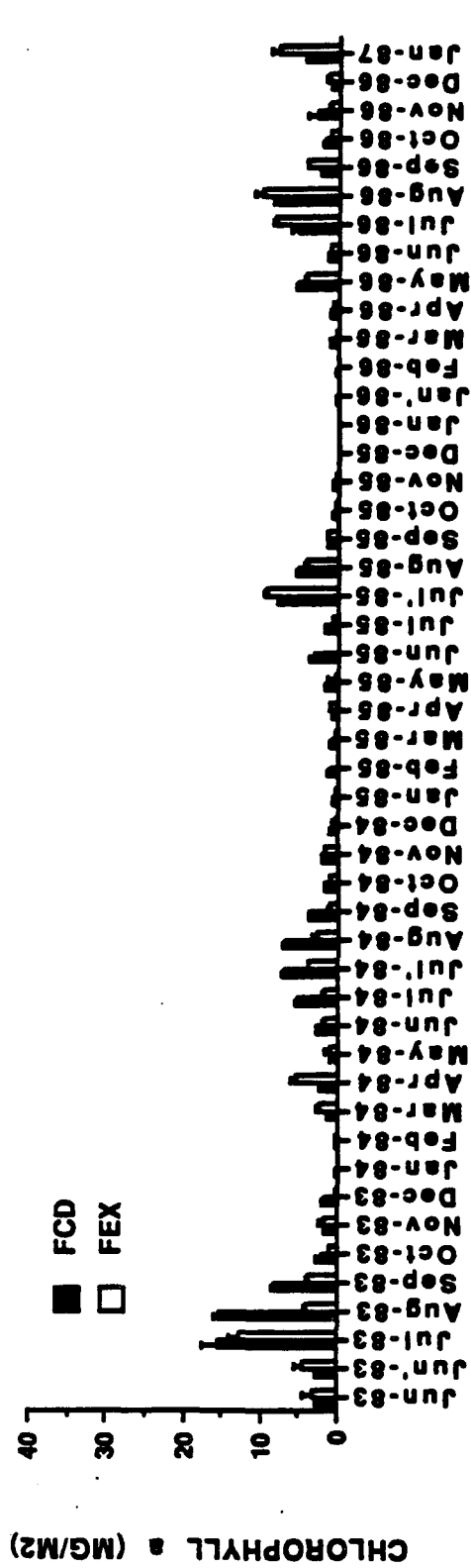


FIGURE 2.1 CHLOROPHYLL a STANDING CROP FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES ON THE FORD RIVER, 1983-1991.

Table 2.1 Chlorophyll a (mg/m²) for Experimental (FEX and FEX-N) and Control (FCD and FCD-N) sites for 1990-1991. Values are Means \pm S.E, N in parentheses.

Date	Experimental		Control	
	FEX	FEX-N	FCD	FCD-N
6/11/90	---	9.52 \pm 1.05 (10)	6.87 \pm 1.27 (10)	6.23 \pm 0.74 (10)
7/9/90	---	9.68 \pm 0.56 (10)	6.32 \pm 0.76 (10)	5.54 \pm 0.84 (10)
8/6/90	9.77 \pm 0.23 (10)	5.99 \pm 0.88 (10)	4.80 \pm 0.43 (10)	4.35 \pm 0.70 (10)
9/4/90	6.88 \pm 0.23 (10)	6.91 \pm 0.49 (10)	4.70 \pm 0.27 (10)	4.86 \pm 0.41 (10)
10/1/90	5.02 \pm 0.27 (10)	5.86 \pm 0.61 (10)	4.55 \pm 0.20 (10)	4.83 \pm 0.47 (10)
10/29/90	1.20 \pm 0.09 (9)	1.14 \pm 0.11 (9)	0.39 \pm 0.17 (10)	0.36 \pm 0.03 (10)
12/10/90	1.06 \pm 0.10 (25)	1.19 \pm 0.08 (24)	2.35 \pm 0.23 (25)	2.17 \pm 0.22 (25)
1/19/91	1.07 \pm 0.09 (25)	0.78 \pm 0.05 (25)	0.73 \pm 0.14 (24)	0.60 \pm 0.05 (24)
3/2/91	0.93 \pm 0.13 (24)	0.86 \pm 0.05 (25)	1.40 \pm 0.06 (25)	1.12 \pm 0.07 (25)
4/22/91	0.74 \pm 0.14 (25)	1.48 \pm 0.17 (25)	3.63 \pm 0.42 (24)	1.80 \pm 0.31 (25)
5/20/91	11.49 \pm 1.35 (10)	13.90 \pm 0.88 (10)	15.47 \pm 0.61 (10)	13.46 \pm 0.87 (10)
6/17/91	5.45 \pm 0.50 (10)	6.12 \pm 0.37 (10)	6.21 \pm 0.49 (10)	2.61 \pm 0.27 (10)
7/15/91	12.32 \pm 1.15 (10)	9.38 \pm 0.86 (10)	2.96 \pm 0.41 (10)	2.74 \pm 0.22 (10)
8/12/91	13.16 \pm 0.53 (10)	14.84 \pm 0.54 (10)	6.33 \pm 0.36 (10)	11.11 \pm 0.43 (10)
9/9/91	13.11 \pm 0.37 (8)	13.40 \pm 0.53 (10)	5.58 \pm 0.42 (10)	8.64 \pm 0.48 (10)

Table 2.2 Paired t-test and Correlations between the Experimental (FEX) and Control (FCD) sites for Biological parameters for June 1990-Sept 1991.

Parameter	df	Paired t-value	Significance (NS = p > 0.05)	Correlation Coefficient	Significance (NS = p > 0.05)
Chlorophyll a	12	-1.540	NS	0.599	p < 0.05
AFDW	12	-2.733	p < 0.05	0.860	p < 0.01
Chlorophyll a daily accrual	12	-1.602	NS	0.668	p < 0.05
AFDW daily accrual	12	-2.715	p < 0.05	0.716	p < 0.01
Species Diversity	14	3.279	p < 0.01	0.963	p < 0.01
Species Evenness	14	2.576	p < 0.05	0.961	p < 0.01
Cell density	14	-3.626	p < 0.01	0.883	p < 0.01
Cell volume	14	1.449	NS	0.792	p < 0.01
Biovolume	14	-2.623	p < 0.05	0.775	p < 0.01

Table 2.3 Paired t-test and Correlations between the Experimental (FEX) and the New Experimental (FEX-N) sites for Biological parameters for June 1990-Sept 1991.

Parameter	df	Paired t-value	Significance (NS = p > 0.05)	Correlation Coefficient	Significance (NS = p > 0.05)
Chlorophyll a	12	0.057	NS	0.948	p < 0.01
AFDW	12	0.452	NS	0.650	p < 0.05
Chlorophyll a daily accrual	12	1.221	NS	0.967	p < 0.01
AFDW daily accrual	12	2.542	p < 0.05	0.885	p < 0.01
Species Diversity	14	0.450	NS	0.940	p < 0.01
Species Evenness	14	0.089	NS	0.946	p < 0.01
Cell density	14	-0.403	NS	0.926	p < 0.01
Cell volume	14	-1.116	NS	0.881	p < 0.01
Biovolume	14	-0.871	NS	0.859	p < 0.01

Table 2.4 Paired t-test and Correlations between the Control (FCD) and the New Control (FCD-N) sites for Biological parameters for June 1990-Sept 1991.

Parameter	df	Paired t-value	Significance (NS = p > 0.05)	Correlation Coefficient	Significance (NS = p > 0.05)
Chlorophyll a	14	0.492	NS	0.861	p < 0.01
AFDW	14	-0.186	NS	0.750	p < 0.01
Chlorophyll a daily accrual	14	0.549	NS	0.652	p < 0.05
AFDW daily accrual	14	0.356	NS	0.844	p < 0.01
Species Diversity	14	0.110	NS	0.971	p < 0.01
Species Evenness	14	0.807	NS	0.963	p < 0.01
Cell density	14	0.192	NS	0.681	p < 0.05
Cell volume	14	1.477	NS	0.881	p < 0.01
Biovolume	14	0.753	NS	0.693	p < 0.01

Table 2.5 Paired t-test and Correlations between the New Experimental (FEX-N) and New Control (FCD-N) sites for Biological parameters for June 1990-Sept 1991.

Parameter	df	Paired t-value	Significance (NS = p > 0.05)	Correlation Coefficient	Significance (NS = p > 0.05)
Chlorophyll a	14	-4.074	p < 0.01	0.917	p < 0.01
AFDW	13	-2.868	p < 0.05	0.810	p < 0.01
Chlorophyll a daily accrual	14	-1.968	NS	0.858	p < 0.01
AFDW daily accrual	14	-2.146	p = 0.05	0.893	p < 0.01
Species Diversity	14	2.765	p < 0.05	0.939	p < 0.01
Species Evenness	14	1.367	NS	0.933	p < 0.01
Cell density	14	-3.626	p < 0.01	0.768	p < 0.01
Cell volume	14	-0.292	NS	0.655	p < 0.05
Biovolume	14	-2.589	p < 0.05	0.803	p < 0.01

Table 2.6 Paired t-test and Correlations between the Experimental (FEX) and Control (FCD) sites for Biological Parameters for 1983-1991.

Parameter	df	Paired t-value	Significance (NS = p > 0.05)	Correlation Coefficient	Significance (NS = p > 0.05)
Chlorophyll a	96	-0.427	NS	0.834	p < 0.01
AFDW	94	-2.443	p < 0.05	0.713	p < 0.01
Chlorophyll a daily accrual	100	-2.026	p < 0.05	0.806	p < 0.01
AFDW daily accrual	99	-1.530	NS	0.599	p < 0.01
Species Diversity	94	2.281	p < 0.05	0.871	p < 0.01
Species Evenness	94	1.976	p < 0.05	0.858	p < 0.01
Cell density	94	-2.512	p < 0.05	0.903	p < 0.01
Cell volume	94	0.734	NS	0.955	p < 0.01
Biovolume	94	-1.811	NS	0.702	p < 0.01

(1984, pg. 153) on the entire data sets and on the summer and winter data sets. The 62% needed to detect a difference between FEX and FCD for the winter data set highlights the variability found in our winter data for chlorophyll *a*. A power analysis conducted on the biological parameters indicated that the ability to detect a change in chlorophyll *a* levels is moderate to poor (Figure 2.2A). For example, at a power of 0.4 one would not be able to detect less than a 25% change in summer chlorophyll *a* levels. The winter data set is even less powerful.

Results of BACI comparisons of 5 year $\log(x+1)$ transformed chlorophyll *a* data (Table 2.8) for the entire data set and the summer data set revealed significant autocorrelations within the data sets according to the Durbin-Watson test of the independence assumption. The winter data set failed Tukey's test for additivity. Thus, randomized intervention analysis (RIA) was used to confirm the results of the BACI comparisons. Results of both the BACI and RIA comparisons indicated that a significant difference ($p < 0.01$) occurred when "before" (6/83-4/86) and "after" (10/89-9/91) means were compared. When broken down on a seasonal basis, the significance was the result of a significant difference between 1983-85/1989-91 summer regressions (Table 2.8). Summer by summer comparisons showed that these differences primarily arose from differences between the summer of 1983 and the summer of 1990, and the summers of 1984 and 1985 and the summers of 1990 and 1991. The difference in the inter-site relationship, detected by both BACI and RIA, is probably due to a differential site response by the algal communities at the two sites to the increase in water temperatures and low flows observed in recent years.

Daily chlorophyll *a* accrual rates followed the same pattern as did standing crop with mid-summer peaks and winter lows (Fig. 2.3, Table 2.9). Daily rates peaked in July, consistent with the pattern observed in the last four years. Paired t-tests between the old and new FEX and FCD sites showed no significant difference in daily accrual rates for June, 1990 to September, 1991 as well as high correlation (Tables 2.2-2.5). However, paired t-tests of 1983 to 1991 data indicate a significant difference between FEX and FCD (Table 2.6). The minimum detectable difference for chlorophyll *a* accrual (Table 2.7) of 32.1% is similar to that for chlorophyll *a* standing crop.

BACI analysis of the chlorophyll *a* accrual rates indicate that there is a difference in the between site relationship "before" impact (6/83-4/86) and that relationship "after" impact (10/89-9/91) (Table 2.8). Since

Table 2.7 Minimum detectable differences for major biological parameters using paired T-tests. Values were computed the complete data set and for summer and winter data sets. Values are % detectable change (at $P < 0.05$)

Parameter	Total	Summer	Winter
Chlorophyll a	29.1	33.5	62.0
Organic matter (AFDW)	22.5	26.3	49.1
Evenness	5.1	6.3	7.2
Cell volume	24.6	23.7	23.2
Biovolume	53.1	59.2	104.2
Density	48.4	51.1	139.1
Diversity	7.4	8.6	11.9
Chlorophyll a Accrual	32.1	37.0	49.8
AFDW Accrual	27.1	29.7	60.8

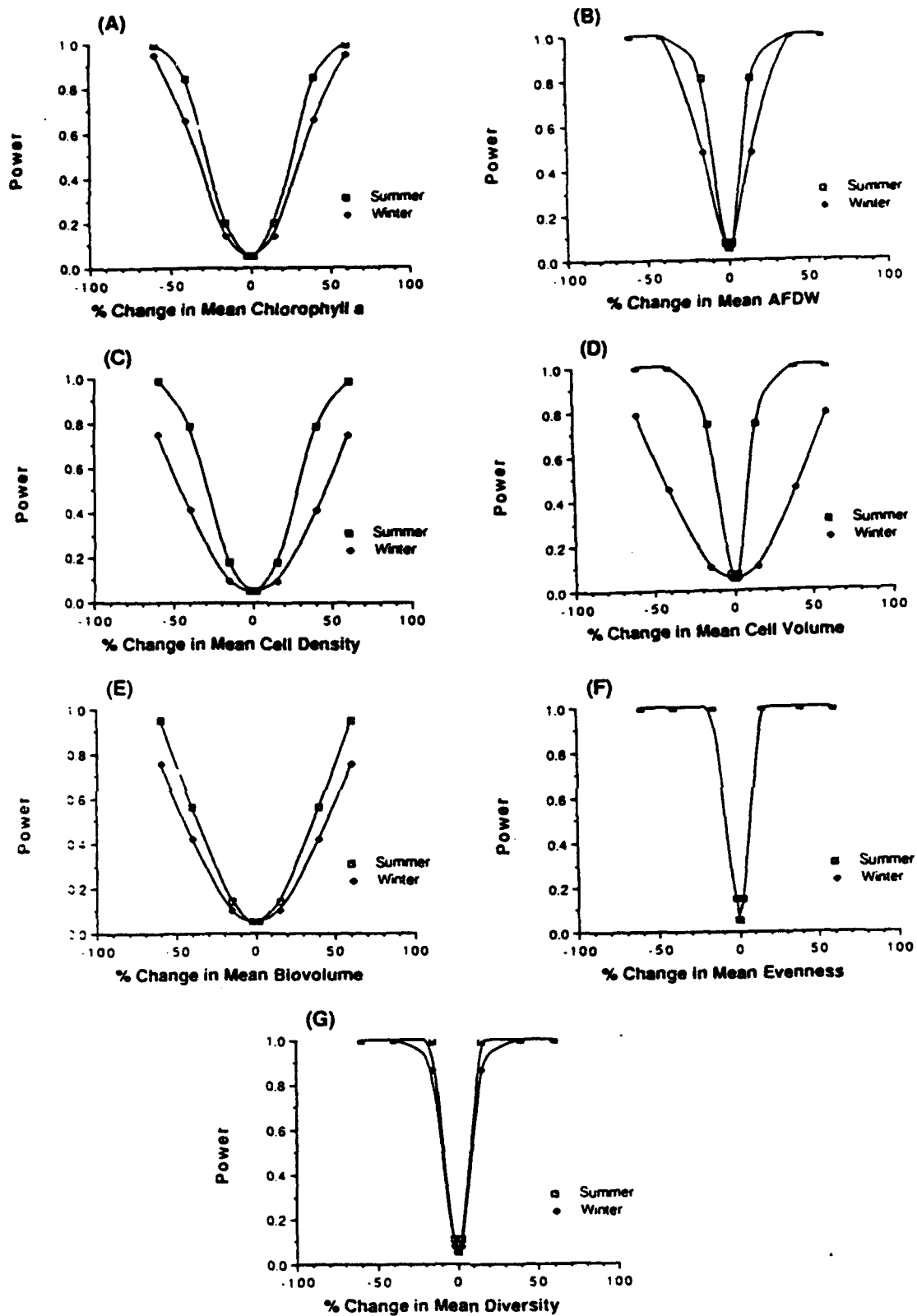


Figure 2.2 Power curves for biological parameters calculated from summer and winter data sets at FCD from 1983-1990; (A) Chlorophyll *a* standing crop, (B) AFDW-Biomass standing crop, (C) Cell Density, (D) Cell Volume, (E) Biovolume, (F) Species Evenness, (G) Species Diversity.

Table 2.8 Summary of BACI and RIA Comparisons for Chlorophyll *a* and AFDW-Biomass between Control (FCD) and Experimental (FEX) Sites for 1983-1991. N in parentheses for BACI and RIA, respectively. RIA results are presented for significant BACI comparisons, or BACI comparisons which did not meet parametric assumptions.

Parameter	Comparison	BACI Signif. ($p < 0.05$)	RIA Signif. ($p < 0.05$)
Chlor. <i>a</i>	6/83-4/86 vs. 10/89-9/91 (59) (59)	$p < 0.01$	$p < 0.01$
	Summer 83-85 vs. 90-91 (32) (34)	$p < 0.01$	$p < 0.01$
	S 83/90 (9)	$p < 0.05$	
	S 84/90 (10)	$p < 0.01$	
	S 84/91 (10)	$p < 0.05$	
	S 85/90 (10)	$p < 0.01$	
	S 85/91 (10)	$p < 0.05$	
	Winter 83-86 vs. 89-90 (25) (27)	NS	NS
Chlor. <i>a</i> Daily Accrual	6/83-4/86 vs. 10/89-9/91 (59) (62)	$p < 0.01$	$p < 0.01$
	Summer 83-85 vs. 90-91 (31) (34)	$p < 0.01$	$p < 0.01$
	S 83/91 (12)	$p < 0.01$	
	S 84/91 (9)	$p < 0.01$	
	S 85/91 (9)	$p < 0.01$	
	S 85/90 (8)	$p < 0.05$	
	Winter 83-86 vs. 89-90 (26)	NS	
AFDW- Biomass	6/83-4/86 vs. 10/89-9/91 (58) (58)	$p < 0.05$	$p < 0.05$
	Summer 83-85 vs. 90-91 (31) (33)	$p < 0.01$	$p < 0.01$
	S 83/91 (9)	$p < 0.05$	
	S 84/91 (10)	$p < 0.01$	
	S 85/91 (10)	$p < 0.05$	
	Winter 83-86 vs. 89-90 (26)	NS	
AFDW- Biomass Daily Accrual	6/83-4/86 vs. 10/89-9/91 (60)	NS	
	Summer 83-85 vs. 90-91 (32)	NS	
	Winter 83-86 vs. 89-90 (26) (27)	NS	NS

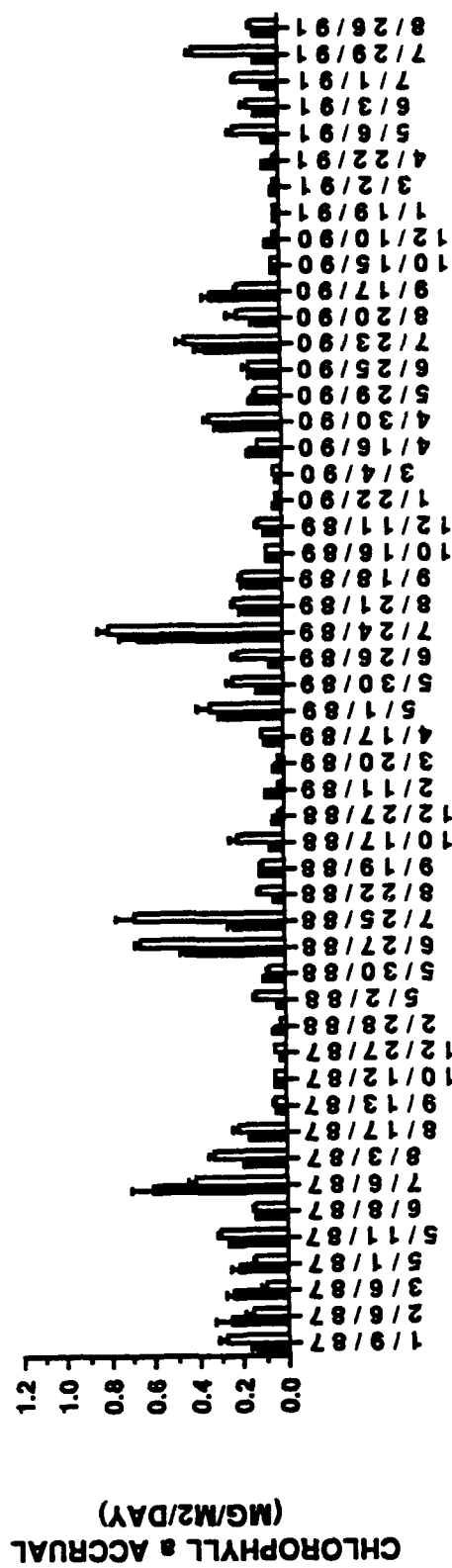
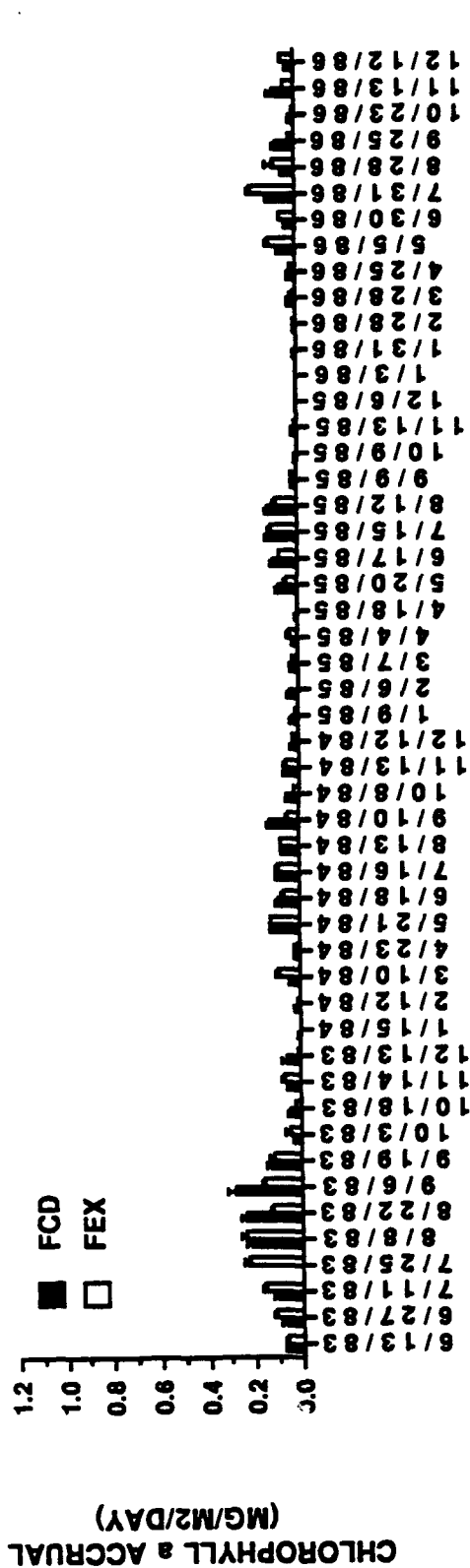


FIGURE 2.3 ACCRUAL RATES OF CHLOROPHYLL a FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES ON THE FORD RIVER, 1983-1991.

Table 2.9 Daily accrual rates of chlorophyll a (mg/m²/d) for Experimental (FEX and FEX-N) and Control (FCD and FCD-N) sites for 1990-1991. Values are Means \pm S.E, N in parentheses.

Date	Experimental		Control	
	FEX	FEX-N	FCD	FCD-N
5/29/90	---	0.11 \pm 0.02 (10)	0.13 \pm 0.01 (10)	0.06 \pm 0.00 (10)
6/25/90	---	0.14 \pm 0.03 (10)	0.12 \pm 0.02 (10)	0.14 \pm 0.01 (10)
7/23/90	0.44 \pm 0.04 (10)	0.45 \pm 0.03 (10)	0.34 \pm 0.04 (10)	0.21 \pm 0.02 (9)
8/20/90	0.19 \pm 0.05 (10)	0.10 \pm 0.01 (10)	0.11 \pm 0.02 (10)	0.17 \pm 0.04 (10)
9/17/90	0.19 \pm 0.02 (10)	0.23 \pm 0.02 (10)	0.31 \pm 0.04 (10)	0.16 \pm 0.02 (10)
10/15/90	0.03 \pm 0.00 (10)	0.03 \pm 0.01 (9)	0.03 \pm 0.00 (10)	0.02 \pm 0.00 (10)
12/10/90	0.03 \pm 0.00 (25)	0.03 \pm 0.00 (24)	0.06 \pm 0.00 (25)	0.05 \pm 0.01 (25)
1/19/91	0.03 \pm 0.00 (25)	0.02 \pm 0.00 (25)	0.02 \pm 0.00 (24)	0.01 \pm 0.00 (24)
3/2/91	0.02 \pm 0.00 (24)	0.02 \pm 0.00 (25)	0.03 \pm 0.00 (25)	0.03 \pm 0.00 (25)
4/22/91	0.02 \pm 0.00 (25)	0.03 \pm 0.00 (25)	0.07 \pm 0.01 (24)	0.04 \pm 0.01 (25)
5/6/91	0.21 \pm 0.02 (10)	0.15 \pm 0.01 (10)	0.07 \pm 0.01 (10)	0.15 \pm 0.02 (10)
6/3/91	0.15 \pm 0.02 (10)	0.17 \pm 0.02 (10)	0.10 \pm 0.02 (10)	0.10 \pm 0.02 (10)
7/1/91	0.19 \pm 0.02 (10)	0.15 \pm 0.01 (10)	0.07 \pm 0.00 (10)	0.06 \pm 0.00 (10)
7/29/91	0.39 \pm 0.02 (10)	0.38 \pm 0.02 (10)	0.10 \pm 0.01 (10)	0.24 \pm 0.01 (10)
8/26/91	0.12 \pm 0.01 (10)	0.09 \pm 0.00 (10)	0.10 \pm 0.02 (10)	0.08 \pm 0.01 (10)

the validity of BACI's independence assumption appeared to be questionable according to the Durbin-Watson test results, RIA was used to confirm the difference detected in the BACI comparison of summers 1983-1985 vs summers 1990-1991 as well as the overall comparison. However, RIA could not confirm yearly comparisons. Based on the BACI comparisons alone, between site differences were due to differences between the summers of 1983, 1984, 1985 (before years) and 1991 (an after year) and the summer of 1985 and that of 1990. Once again, this change in the inter-site relationship may be related to weather differences between these years.

C. Patterns of Organic Matter Accumulation

Organic matter measured as accumulation of ash free dry weight (AFDW) on glass slides generally followed the same trends in 1990-1991 as did chlorophyll a (Figs. 2.1, 2.4). The annual pattern for organic matter standing crop was similar to that of previous years except the summer of 1990 when lower levels probably resulted from a return to pre-drought temperatures (Table 2.10). Generally, FEX-N and FCD-N paralleled organic matter standing crop levels at FEX and FCD from June, 1990 to September, 1991.

Paired t-tests between the FEX and FCD sites for AFDW-organic matter accumulation showed significant differences for June, 1990-September, 1991 data (Tables 2.2) and the data taken since 1983 (Table 2.6), but the sites were significantly correlated during both time periods. Comparisons involving the new FEX and FCD sites from June, 1990 to September, 1991 (Tables 2.3-2.5) showed no significant differences between FEX vs FEX-N and FCD vs FCD-N, as well as significant correlation (Tables 2.3 and 2.4). FEX-N vs FCD-N were also correlated, but indicated significant differences between sites (Table 2.5). BACI analyses conducted on AFDW-organic matter standing crop data (Table 2.8) indicated that a difference in the between site relationship "before" impact (6/83-4/86) and that relationship "after" impact (10/89-9/91) occurred for the entire data set and for the summer data. RIA confirmed results obtained for the BACI analyses of summer and pooled comparisons. Yearly summer BACI comparisons indicate differences between the summers of 1983, 1984, 1985 (before years) and the summer of 1991 (an after year).

The minimum detectable difference for AFDW-organic matter is 22.5% for the entire data set, 26% for the summer data set and 49.1% for the winter data set (Table 2.7). The high winter value is due to the high variability in our winter data sets. The two sites tend to experience different winter conditions, i.e. FEX tends to freeze over quicker than FCD and often will be frozen over while FCD remains open.

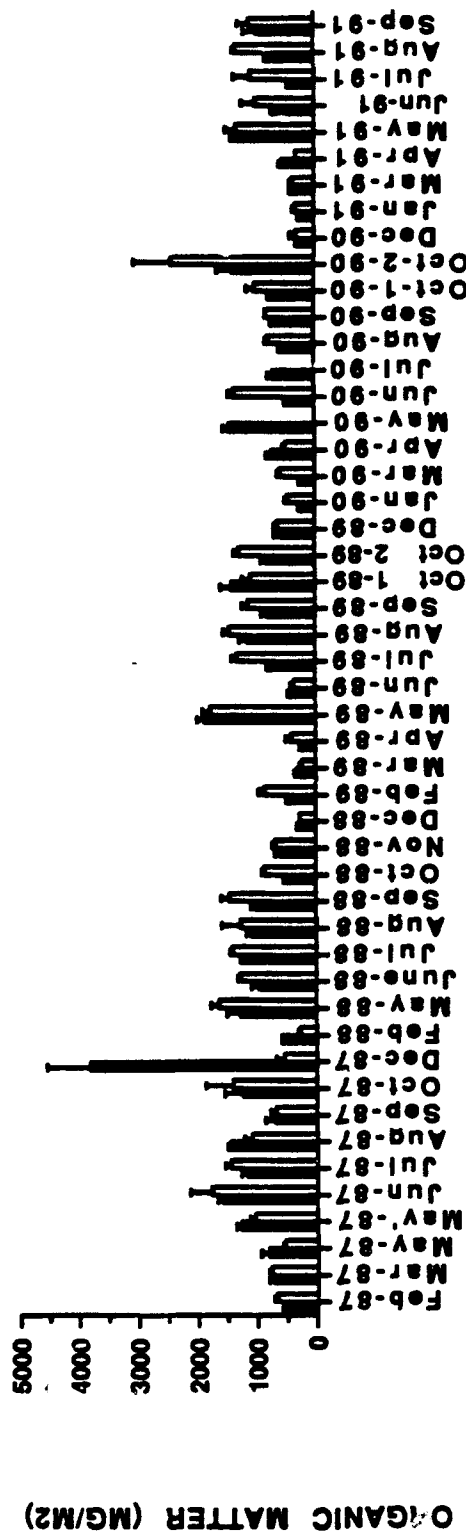


FIGURE 2.4 ORGANIC MATTER STANDING CROP FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES ON THE FORD RIVER, 1983-1991.

Table 2.10 Ash Free Dry Weight Biomass (mg/m²) for Experimental (FEX and FEX-N) and Control (FCD and FCD-N) sites for 1990-1991. Values are Means \pm S.E., N in parentheses.

Date	Experimental		Control	
	FEX	FEX-N	FCD	FCD-N
6/11/90	---	1368 \pm 96 (7)	461 \pm 50 (10)	541 \pm 24 (10)
7/9/90	---	---	673 \pm 79 (8)	240 \pm 107 (7)
8/6/90	781 \pm 54 (10)	605 \pm 28 (10)	549 \pm 26 (10)	522 \pm 22 (10)
9/4/90	797 \pm 62 (10)	947 \pm 67 (10)	672 \pm 37 (10)	624 \pm 44 (10)
10/1/90	1013 \pm 134 (10)	1459 \pm 94 (10)	709 \pm 85 (10)	896 \pm 96 (10)
10/29/90	2411 \pm 620 (10)	990 \pm 100 (9)	1368 \pm 262 (10)	789 \pm 160 (10)
12/10/90	320 \pm 74 (24)	360 \pm 72 (25)	278 \pm 48 (25)	356 \pm 54 (25)
1/19/91	337 \pm 28 (25)	403 \pm 84 (25)	226 \pm 34 (25)	343 \pm 52 (25)
3/2/91	350 \pm 44 (25)	420 \pm 24 (24)	386 \pm 35 (25)	246 \pm 30 (24)
4/22/91	304 \pm 35 (24)	295 \pm 28 (20)	532 \pm 52 (22)	573 \pm 53 (21)
5/20/91	1139 \pm 153 (10)	1576 \pm 114 (10)	1307 \pm 108 (10)	1368 \pm 107 (10)
6/17/91	1022 \pm 186 (10)	1024 \pm 65 (10)	715 \pm 26 (10)	907 \pm 215 (8)
7/15/91	1090 \pm 69 (10)	803 \pm 55 (10)	429 \pm 24 (10)	600 \pm 35 (10)
8/12/91	1309 \pm 61 (10)	1464 \pm 50 (10)	805 \pm 35 (10)	1109 \pm 35 (10)
9/9/91	1107 \pm 54 (10)	1107 \pm 160 (10)	941 \pm 229 (10)	1107 \pm 137 (10)

Based on a power curve of AFDW-organic matter, the ability to detect a relatively small change in the mean AFDW is fairly high, however, the winter data set proved to be less powerful than the summer data set (Figure 2.2B).

Organic matter accrual rates (Figure 2.5 and Table 2.11) followed a pattern of winter lows and summer highs similar to the pattern followed by organic matter standing crop. The accrual rates for the FEX and FCD sites were not significantly different in 1990-91 and were significantly correlated between sites (Table 2.2). Overall, there was no significant difference in organic matter accrual rates between the two sites, and the data were highly correlated between sites (Table 2.6). Paired t-tests of the new and old sites from June, 1990 to September, 1991 (Tables 2.3-2.5) indicate significant differences for FEX vs FEX-N and FEX-N vs FCD-N comparisons. The minimum detectable difference for organic matter accrual was 27.1% (Table 2.7), similar to the value for organic matter standing crop. BACI analysis on AFDW-organic matter accrual (Table 2.8) indicated that there were no differences in the between site relationship "before" testing began on the antenna in May of 1986 and "after" full operation in October of 1989, a result corroborated by randomized intervention analysis (Table 2.8).

D. Patterns of Diatom Cell Density

Diatom cell density reached its lowest level during the winter for each of the years studied at each site (Fig. 2.6). Typically, the lowest values occurred in January or February when the Ford River was ice covered with limited light penetration and with water temperatures near 0°C. The winter season from late October until April was characterized by diminished levels of diatom density. Actual values ranged from 10^7 to 10^8 cells/m². The peak values for diatom cell density occurred at less predictable intervals (Fig. 2.6). The highest monthly densities of cells were reported in August 1983, June 1984, June 1985, May 1986, May 1987, May 1988 and 1989, May - July of 1990 and May 1991 (Fig. 2.6). Thus, the highest cell densities measured were found to occur anytime within a four month spring-summer period. The duration of continued high cell densities also varied by year (Fig. 2.6); sometimes continuing throughout the summer, and at other times restricted to only one or two months of very high densities, e.g., May 1986. In 1991, the pattern was for lowest cell densities in the winter and for greatest densities in the spring and/or summer (Fig. 2.6, Table 2.12). However, FCD returned to near winter values almost immediately after its May peak. Data from FEX-N and FCD-N sites from June, 1990 to September, 1991 followed the patterns apparent at FEX and FCD in most cases (Table 2.12).

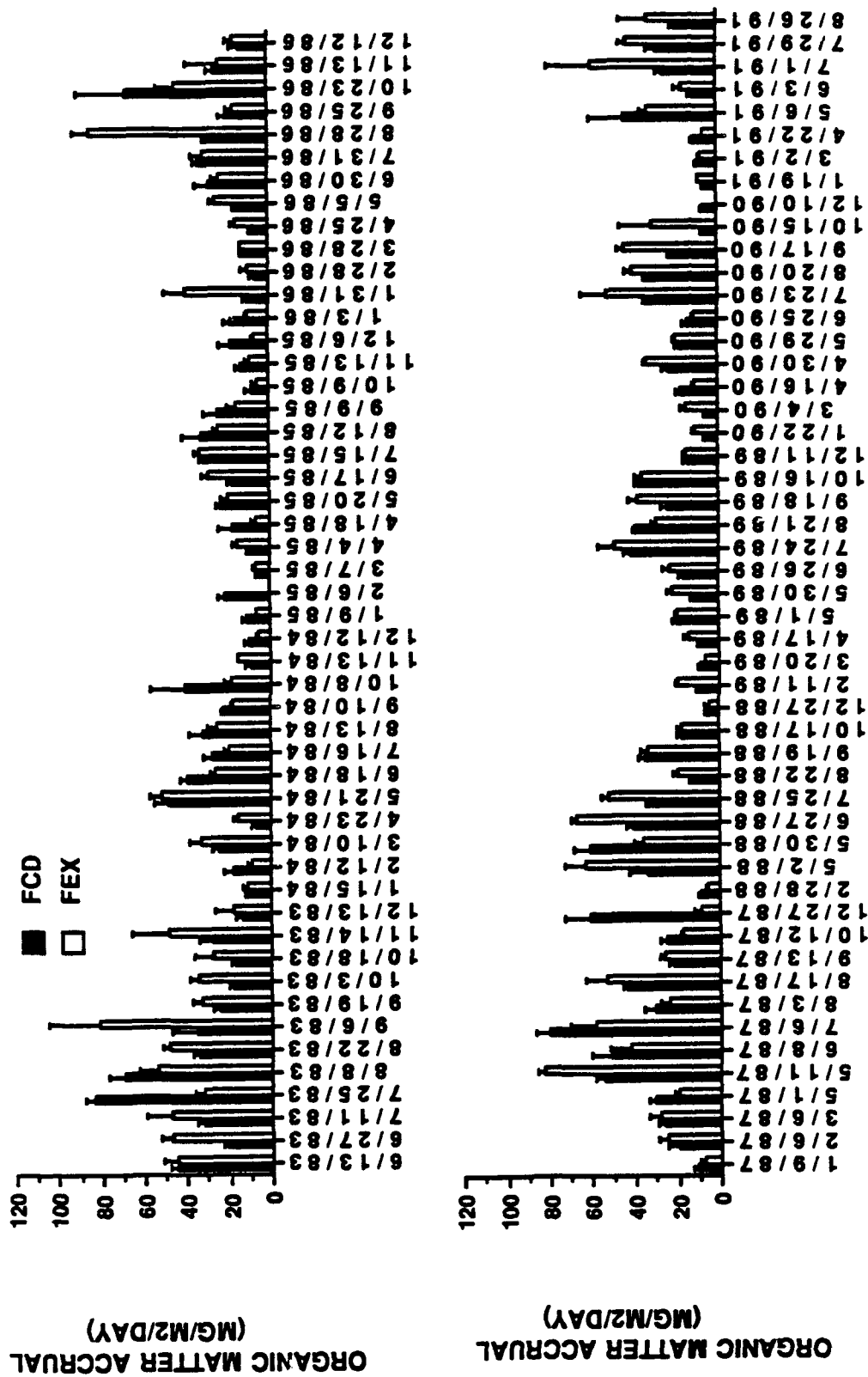


FIGURE 2.5 ACCRUAL RATES OF ORGANIC BIOMASS FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES ON THE FORD RIVER, 1983-1991.

Table 2.11 Daily accrual rates of AFDW-Biomass (mg/m²/d) for Experimental (FEX and FEX-N) and Control (FCD and FCD-N) sites for 1990-1991. Values are Means \pm S.E., N in parentheses.

Date	Experimental		Control	
	FEX	FEX-N	FCD	FCD-N
5/29/90	---	19 \pm 2 (10)	17 \pm 3 (9)	12 \pm 1 (10)
6/25/90	---	11 \pm 1 (10)	14 \pm 2 (10)	14 \pm 2 (11)
7/23/90	52 \pm 12 (10)	53 \pm 6 (10)	33 \pm 2 (10)	33 \pm 4 (9)
8/20/90	40 \pm 3 (10)	32 \pm 4 (10)	33 \pm 2 (10)	33 \pm 2 (10)
9/17/90	43 \pm 4 (10)	25 \pm 3 (10)	22 \pm 1 (10)	22 \pm 3 (10)
10/15/90	31 \pm 15 (10)	16 \pm 2 (10)	6 \pm 2 (10)	5 \pm 1 (10)
12/10/90	8 \pm 1 (24)	9 \pm 1 (25)	7 \pm 1 (25)	8 \pm 1 (25)
1/19/91	8 \pm 0 (25)	10 \pm 1 (25)	6 \pm 1 (25)	8 \pm 1 (25)
3/2/91	8 \pm 1 (25)	10 \pm 1 (24)	9 \pm 1 (25)	6 \pm 1 (24)
4/22/91	6 \pm 1 (24)	6 \pm 1 (20)	11 \pm 1 (22)	12 \pm 1 (21)
5/6/91	32 \pm 3 (10)	22 \pm 3 (10)	43 \pm 16 (10)	24 \pm 2 (10)
6/3/91	16 \pm 3 (10)	17 \pm 2 (10)	12 \pm 2 (10)	13 \pm 1 (10)
7/1/91	59 \pm 20 (10)	38 \pm 5 (10)	25 \pm 3 (10)	32 \pm 10 (10)
7/29/91	42 \pm 3 (10)	44 \pm 3 (10)	28 \pm 5 (10)	36 \pm 4 (10)
8/26/91	33 \pm 12 (10)	18 \pm 2 (10)	20 \pm 2 (10)	17 \pm 2 (10)

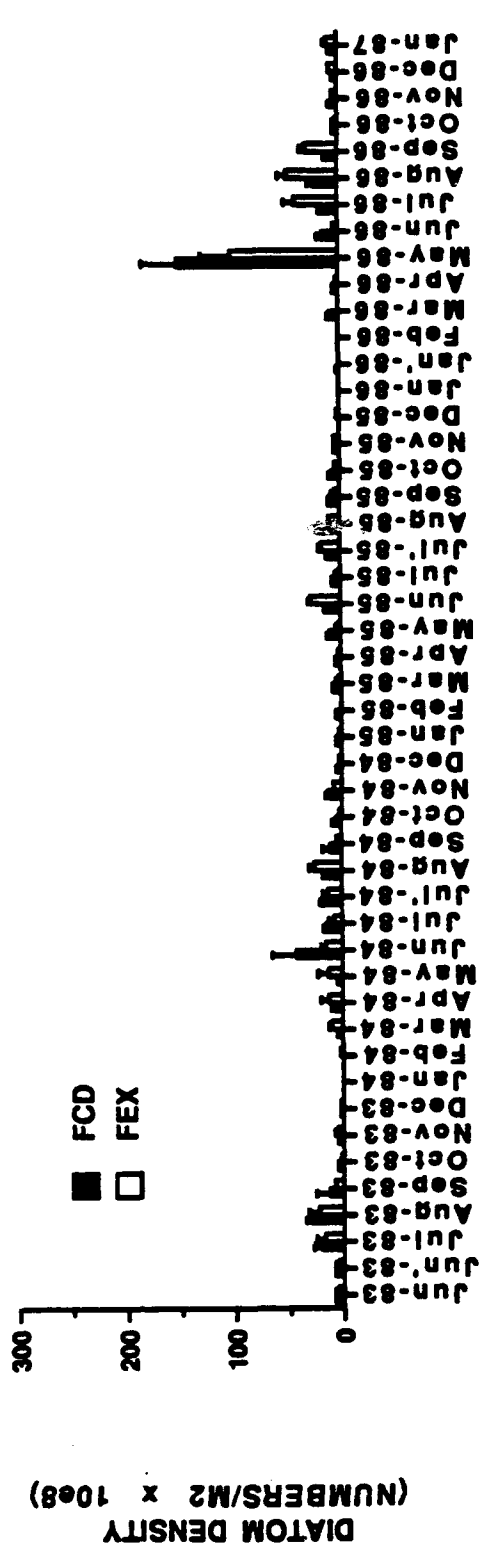


FIGURE 2.6 DIATOM CELL DENSITIES FOR THE FORD RIVER, 1983-1991.

Table 2.12 Cell Density (cells/m² x 10⁸) for Experimental (FEX and FEX-N) and Control (FCD and FCD-N) sites for 1990-1991. Values are Means \pm S.E., N in parentheses.

Date	Experimental			Control		
	FEX	FEX-N	FCD	FCD-N	FCD-N	FCD-N
6/11/90	---	72.96 \pm 4.32 (3)	42.21 \pm 3.85 (3)	74.76 \pm 6.50 (3)		
7/9/90	---	85.78 \pm 26.59 (2)	52.90 \pm 4.96 (2)	27.32 \pm 2.05 (2)		
8/6/90	56.83 \pm 3.17 (3)	53.49 \pm 3.43 (3)	64.30 \pm 6.96 (3)	23.08 \pm 2.66 (3)		
9/4/90	61.74 \pm 3.26 (3)	44.67 \pm 0.77 (3)	32.82 \pm 4.22 (3)	31.06 \pm 5.05 (3)		
10/1/90	33.68 \pm 4.19 (3)	46.73 \pm 5.15 (3)	20.51 \pm 0.59 (3)	28.61 \pm 2.94 (3)		
10/29/90	17.80 \pm 1.72 (3)	17.78 \pm 0.87 (3)	3.05 \pm 0.27 (3)	4.94 \pm 0.14 (3)		
12/10/90	12.68 \pm 0.77 (6)	7.43 \pm 0.22 (6)	4.19 \pm 0.18 (6)	7.20 \pm 0.35 (6)		
1/19/91	2.05 \pm 0.12 (6)	3.47 \pm 0.19 (6)	2.32 \pm 0.12 (6)	1.80 \pm 0.10 (6)		
3/2/91	6.21 \pm 0.24 (6)	4.03 \pm 0.18 (6)	3.84 \pm 0.12 (6)	3.84 \pm 0.17 (6)		
4/22/91	5.34 \pm 0.15 (6)	5.38 \pm 0.14 (6)	3.79 \pm 0.20 (6)	5.04 \pm 0.18 (6)		
5/20/91	55.43 \pm 5.02 (3)	47.99 \pm 5.93 (3)	31.70 \pm 1.11 (3)	31.11 \pm 4.29 (3)		
6/17/91	14.11 \pm 1.79 (3)	37.41 \pm 5.69 (3)	5.18 \pm 0.68 (3)	5.06 \pm 0.40 (3)		
7/15/91	42.12 \pm 2.24 (3)	32.44 \pm 3.13 (3)	6.42 \pm 0.32 (3)	4.70 \pm 0.10 (3)		
8/12/91	12.85 \pm 3.57 (3)	31.73 \pm 3.53 (3)	4.09 \pm 0.28 (3)	17.12 \pm 1.07 (3)		
9/9/91	5.10 \pm 0.25 (3)	9.84 \pm 0.42 (3)	4.15 \pm 0.17 (3)	4.02 \pm 0.33 (3)		

Paired t-tests demonstrated that site differences in cell densities were significant at FEX and FCD for June, 1990-September, 1991 (Table 2.2) and for all the data collected since 1983 (Table 2.6) but cell density at FEX was closely correlated with cell density at FCD (Tables 2.2, 2.6). Results of paired t-tests which include the new sites and data from June, 1990 to September, 1991 showed no significant differences in cell densities for FEX vs FEX-N and FCD vs FCD-N (Tables 2.3 and 2.4), but significant differences for FEX-N vs FCD-N (Tables 2.5). However, all comparisons indicated significant correlation between sites. BACI results from the overall 5 year cell density data indicated a significant difference between "before" (6/83-4/86) and "after" (10/89-9/91) periods (Table 2.13). Further analysis suggested that the summer variations were responsible for this significant result. The between site relationship for cell density for the summer of 1983 was different than it was for the summers of 1990 and 1991, and the summers of 1984 and 1985 differed from the summer of 1991. This difference was also detected by RIA (Table 2.13). Cell density is highly variable, (Figure 2.6) resulting in a rather large (approximately 50%) minimum detectable difference (Table 2.7). Power analysis of cell density indicate that the data are only moderately powerful, similar to the chlorophyll a power analysis, and the winter data set even less powerful (Figure 2.2C).

E. Patterns in Individual Cell Volume and Total Biovolume

Individual cell volumes for the 8.5 year period (Fig. 2.7, Table 2.14) were characterized by a trend towards larger volumes of diatoms in the periphyton occurring during the colder, winter months of November through March and smaller diatoms occurring during the summer months. The 1987-88 cell volume data did not follow this pattern however. Following the dramatic rise in mean cell volume during the winter of 1986-87 associated with dominance by Synedra and Diatoma, values dropped off during the spring-summer and remained low over the winters of 1987-88 and 1988-89. The cell volume for the winter of 1989-90 returned to the levels seen before 1986-87 and the winter of 1990-91 followed the same pattern.

Paired t-tests and correlations showed that mean cell volume was not significantly different for any of the new and old FEX and FCD site comparisons (Tables 2.2-2.5) for June, 1990-September, 1991, as well as for all data at FEX and FCD collected since 1983 (Table 2.6). BACI and RIA comparisons of cell volume indicated that "before" data were not different from "after" data either on an overall basis or for any summer or winter season comparisons (Table 2.14).

Table 2.13 Summary of BACI and RIA Comparisons for Density, Volume, Biovolume, Diversity and Evenness between Control (FCD) and Experimental (FEX) Sites for 1983-1991. N in parentheses for BACI and RIA, respectively. RIA results are presented for significant BACI comparisons, or BACI comparisons which did not meet parametric assumptions.

Parameter	Comparison	BACI Signif. (p < 0.05)	RIA Signif. (p < 0.05)
Cell Density	6/83-4/86 vs. 10/89-9/91 (59) (61)	p < 0.01	p < 0.01
	Summer 83-85 vs. 90-91 (32) (34)	p < 0.01	p < 0.01
	S 83/90 (9)	p < 0.05	
	S 83/91 (9)	p < 0.01	
	S 84/91 (10)	p < 0.05	
	S 85/91 (10)	p < 0.01	
	Winter 83-86 vs. 89-90 (25) (27)	NS	NS
Cell Volume	6/83-4/86 vs. 10/89-9/91 (59) (61)	NS	NS
	Summer 83-85 vs. 90-91 (32)	NS	
	Winter 83-86 vs. 89-90 (27)	NS	
Biovolume	6/83-4/86 vs. 10/89-9/91 (59) (61)	p < 0.01	p < 0.05
	Summer 83-85 vs. 90-91 (32) (34)	p < 0.05	p < 0.05
	S 85/91 (10)	p < 0.05	
	Winter 83-86 vs. 89-90 (27) (27)	NS	NS
Species Diversity	6/83-4/86 vs. 10/89-9/91 (59)	NS	
	Summer 83-85 vs. 90-91 (32)	NS	
	Winter 83-86 vs. 89-90 (25)	NS	
Species Evenness	6/83-4/86 vs. 10/89-9/91 (59) (61)	p < 0.01	p < 0.05
	Summer 83-85 vs. 90-91 (32)	NS	
	Winter 83-86 vs. 89-90 (25) (27)	p < 0.01	p < 0.01
	W 83/90 (8)	p < 0.05	
	W 84/90 (8)	p < 0.05	
	W 85/90 (9)	p < 0.05	
Gross Primary Production	7/84-8/85 vs. 6/89-8/91 (29)	NS	

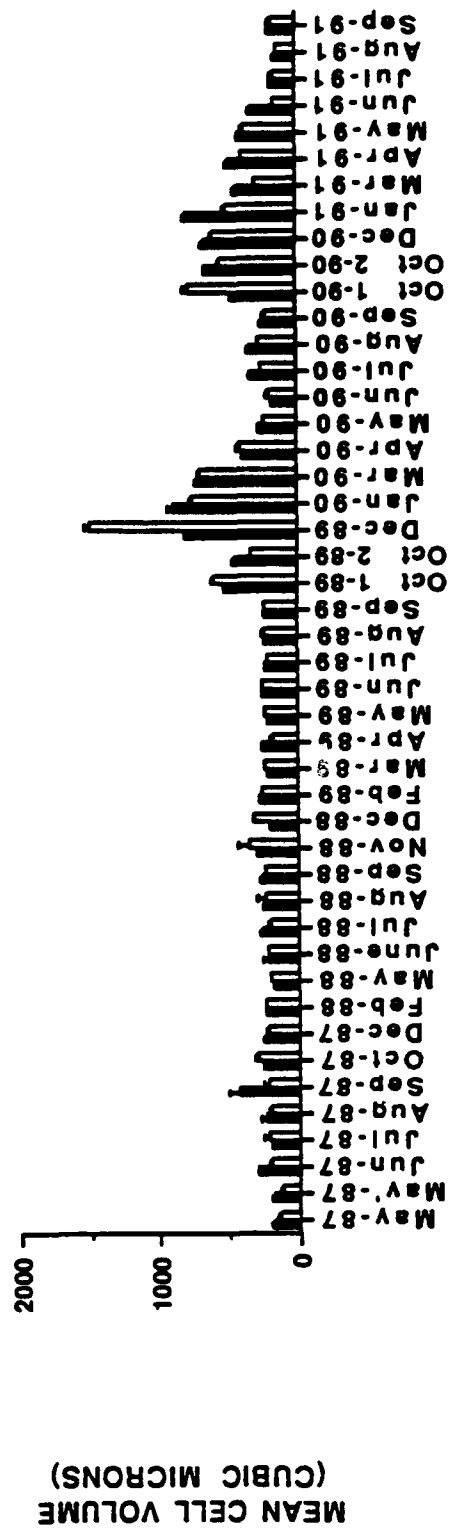
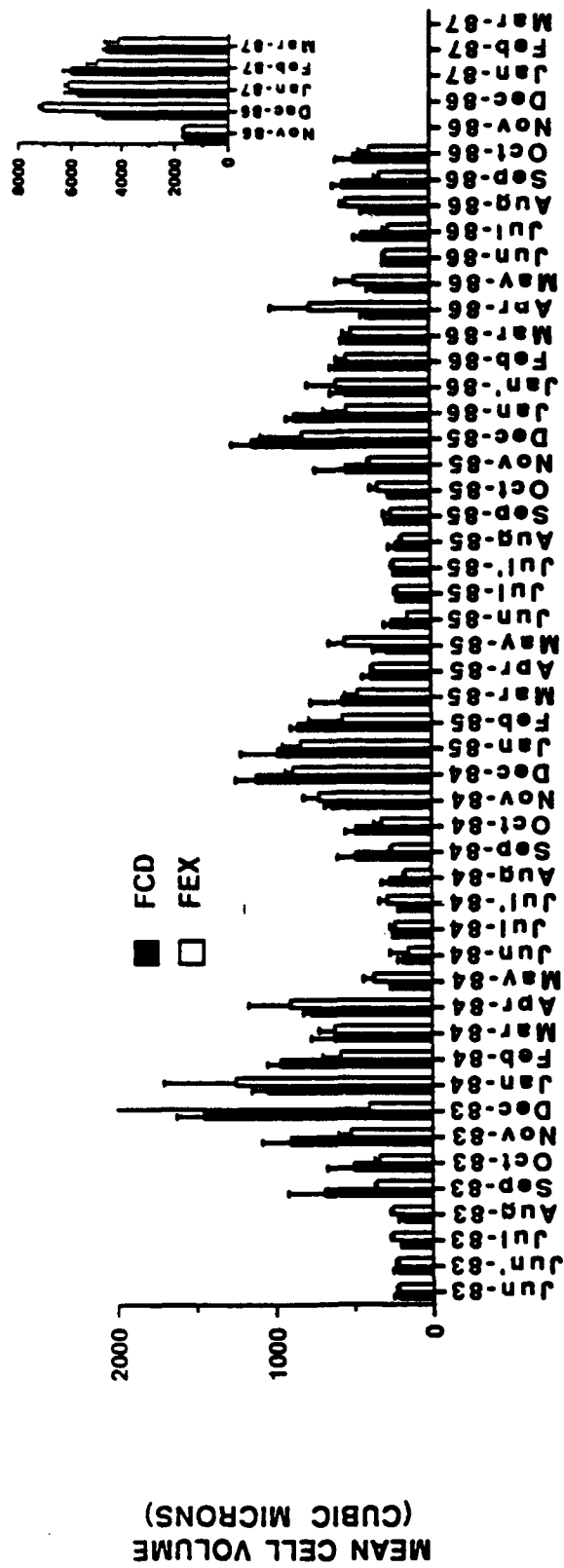


FIGURE 2.7 INDIVIDUAL CELL SIZES FOR THE FORD RIVER, 1983-1991.

Table 2.14 Average Individual Diatom Cell Volume (cubic micrometers) for Experimental (FEX and FEX-N) and Control (FCD and FCD-N) sites for 1990-1991. Values are Means \pm S.E, N in parentheses.

Date	Experimental		Control	
	FEX	FEX-N	FCD	FCD-N
6/11/90	---	187.5 \pm 22.7 (3)	172.8 \pm 1.3 (3)	240.5 \pm 71.1 (3)
7/9/90	---	243.6 \pm 3.8 (2)	328.5 \pm 1.6 (2)	300.5 \pm 108.6 (2)
8/6/90	268.2 \pm 10.0 (3)	511.2 \pm 18.4 (3)	326.8 \pm 15.1 (3)	286.2 \pm 17.9 (3)
9/4/90	222.9 \pm 17.2 (3)	148.4 \pm 13.0 (3)	232.8 \pm 10.9 (3)	208.2 \pm 3.4 (3)
10/1/90	778.5 \pm 33.7 (3)	971.0 \pm 63.9 (3)	460.8 \pm 8.4 (3)	483.4 \pm 28.1 (3)
10/29/90	551.7 \pm 18.5 (3)	486.9 \pm 24.6 (3)	651.0 \pm 14.7 (3)	534.2 \pm 13.5 (3)
12/10/90	599.3 \pm 20.5 (6)	488.9 \pm 10.5 (6)	667.5 \pm 17.2 (6)	517.2 \pm 20.2 (6)
1/19/91	512.6 \pm 19.2 (6)	520.5 \pm 9.0 (6)	793.6 \pm 20.0 (6)	870.8 \pm 12.9 (6)
3/2/91	287.0 \pm 6.5 (6)	471.9 \pm 11.2 (6)	434.4 \pm 10.6 (6)	470.6 \pm 12.0 (6)
4/22/91	382.3 \pm 7.1 (6)	545.5 \pm 8.4 (6)	489.2 \pm 11.0 (6)	402.0 \pm 16.2 (6)
5/20/91	370.6 \pm 8.1 (3)	325.0 \pm 11.5 (3)	398.8 \pm 11.7 (3)	240.2 \pm 8.9 (3)
6/17/91	161.1 \pm 2.2 (3)	176.8 \pm 7.4 (3)	305.9 \pm 21.6 (3)	213.5 \pm 2.8 (3)
7/15/91	161.4 \pm 11.4 (3)	123.8 \pm 4.8 (3)	163.6 \pm 12.0 (3)	163.4 \pm 7.8 (3)
8/12/91	137.6 \pm 5.7 (3)	188.1 \pm 6.0 (3)	140.5 \pm 9.1 (3)	186.9 \pm 9.1 (3)
9/9/91	178.9 \pm 17.8 (3)	133.0 \pm 7.6 (3)	190.6 \pm 13.0 (3)	200.7 \pm 11.7 (3)

However, since the "before" data was not additive for most of these comparisons, the BACI t-test cannot be considered valid (Stewart-Oaten 1986). Although cell volume is fairly variable between years (Fig. 2.6), it remains fairly consistent between sites resulting in a relatively low (approximately 25%) minimum detectable difference (Table 2.7). A power curve of the summer mean cell volume data indicates a relatively high ability to detect small changes in cell volume (Figure 2.2D). By comparison, the winter data are much less powerful.

Total biovolume for 1991 was highest in May at both FEX and FCD (Fig. 2.8, Table 2.15). The biovolume levels for 1991 declined immediately, unlike the trend of the past few years. Both density (Fig. 2.6) and biovolume (Fig. 2.8) have been characterized by substantially larger spring-summer peak values since May 1986, apparently as a result of the very dry months of May since that time. The rapid decline after May in 1991 may be a result of a return to a wetter May. Total biovolume at all sites varied considerably during the months of August and September between 1990 and 1991. This difference corresponded to a large decrease in cell densities during August and September, 1991. There is no apparent reason why this drop in densities occurred, but see discussion of Cocconeis abundances in section F of this element. The large biovolume peak observed during the 1986-87 winter has not been repeated consistently due to the absence of the large species, Synedra ulna. The presence of Synedra again during winter 1989-90 produced a peak in biovolume, although not of the same magnitude as that seen during winter 1986-87 (Fig. 2.8).

A comparison of total biovolume between sites with the paired t-test showed that biovolume at FEX was significantly different ($p < 0.05$) from biovolume at FCD for the June, 1990-September, 1991 data (Table 2.2), but not for all data collected since 1983 (Table 2.6). Biovolume at FEX was significantly ($p < 0.05$) correlated with biovolume at FCD in 1990-91 (Table 2.2), and for all the data collected since 1983 (Table 2.6). Comparisons of FEX vs FEX-N and FCD vs FCD-N from June, 1990 to September, 1991 indicated no significant difference occurred in biovolume between sites (Tables 2.3 and 2.4). A paired t-test of FEX-N vs FCD-N during the same period, however, showed a significant difference in biovolume between the sites (Table 2.5). Biovolumes at FEX and FEX-N were significantly correlated with biovolumes at FCD and FCD-N, respectively. BACI and RIA comparisons of biovolume demonstrated that there was a significant difference in the between site relationship "before" May, 1986 and "after" October, 1989 (Table 2.13). The difference is due to differences between the summer of 1985 and the summer of 1991. Since the entire data set and

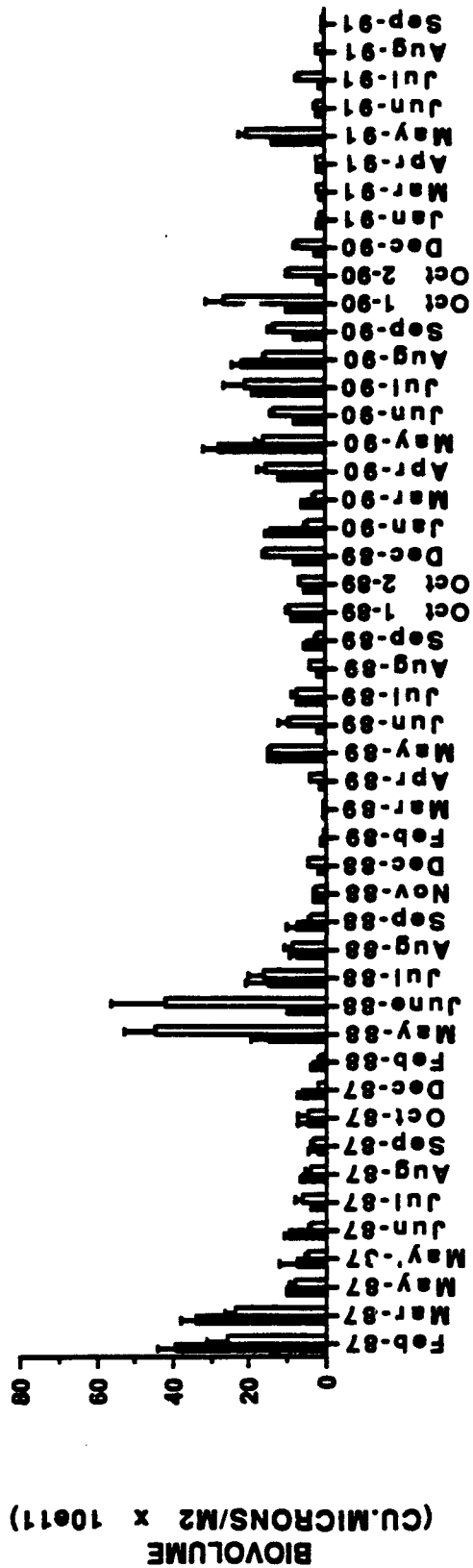
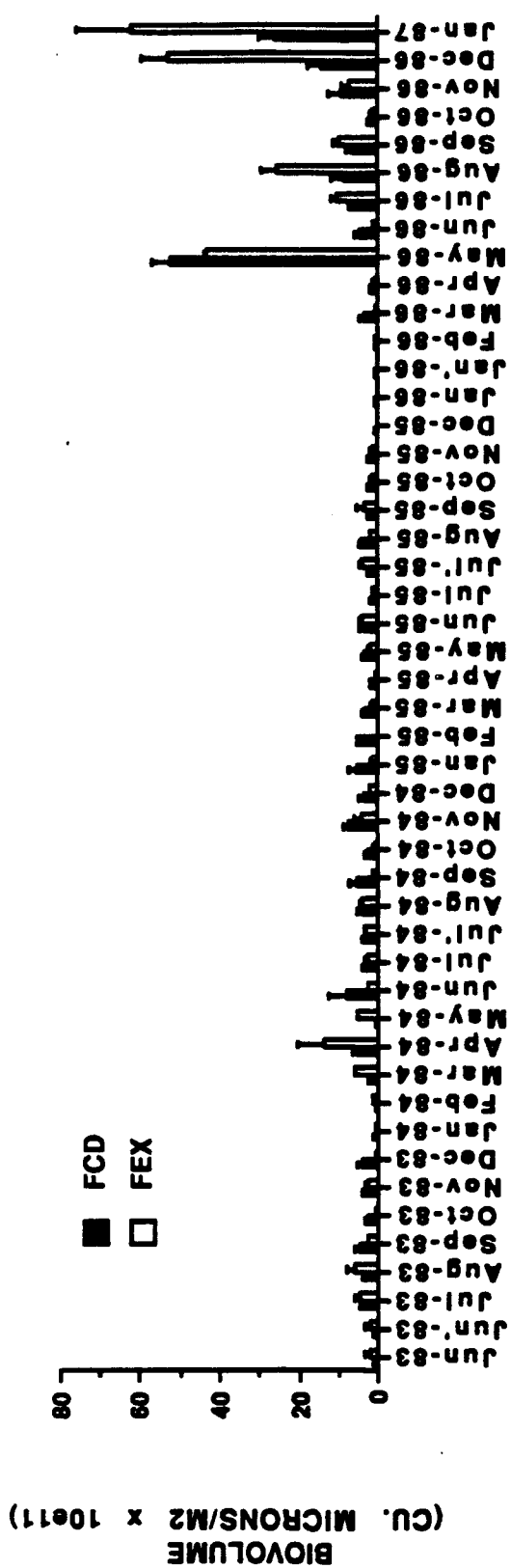


FIGURE 2.8 DIATOM BIOVOLUME FOR THE FORD RIVER, 1983-1991.

Table 2.15 Cell Biovolume (cubic micrometers/ $\text{m}^2 \times 10^{11}$) for Experimental (FEX and FEX-N) and Control (FCD and FCD-N) sites for 1990-1991. Values are Means \pm S.E, N in parentheses.

Date	Experimental		Control	
	FEX	FEX-N	FCD	FCD-N
6/11/90	---	13.48 \pm 0.94 (3)	7.33 \pm 0.66 (3)	12.40 \pm 1.44 (3)
7/9/90	---	21.00 \pm 6.81 (2)	17.37 \pm 1.92 (2)	11.96 \pm 0.06 (2)
8/6/90	15.26 \pm 1.19 (3)	27.23 \pm 1.00 (3)	21.39 \pm 3.15 (3)	6.59 \pm 0.81 (3)
9/4/90	13.78 \pm 1.32 (3)	6.63 \pm 0.62 (3)	7.60 \pm 0.82 (3)	6.49 \pm 1.13 (3)
10/1/90	26.49 \pm 4.50 (3)	45.46 \pm 5.84 (3)	9.46 \pm 0.45 (3)	13.66 \pm 0.62 (3)
10/29/90	9.67 \pm 0.63 (3)	8.62 \pm 0.26 (3)	2.00 \pm 0.15 (3)	2.64 \pm 0.10 (3)
12/10/90	7.56 \pm 0.36 (6)	3.63 \pm 0.12 (6)	2.79 \pm 0.12 (6)	3.71 \pm 0.21 (6)
1/19/91	1.05 \pm 0.08 (6)	1.81 \pm 0.11 (6)	1.95 \pm 0.17 (6)	1.56 \pm 0.08 (6)
3/2/91	1.78 \pm 0.05 (6)	1.91 \pm 0.11 (6)	1.66 \pm 0.03 (6)	1.81 \pm 0.10 (6)
4/22/91	2.04 \pm 0.07 (6)	2.93 \pm 0.09 (6)	1.86 \pm 0.13 (6)	2.04 \pm 0.14 (6)
5/20/91	20.21 \pm 2.14 (3)	15.74 \pm 2.52 (3)	12.66 \pm 0.79 (3)	7.52 \pm 1.24 (3)
6/17/91	2.28 \pm 0.30 (3)	6.60 \pm 1.03 (3)	1.58 \pm 0.23 (3)	1.08 \pm 0.10 (3)
7/15/91	6.85 \pm 0.86 (3)	4.03 \pm 0.52 (3)	1.05 \pm 0.06 (3)	0.77 \pm 0.02 (3)
8/12/91	1.79 \pm 0.53 (3)	5.99 \pm 0.81 (3)	0.58 \pm 0.08 (3)	3.20 \pm 0.24 (3)
9/9/91	0.91 \pm 0.07 (3)	1.31 \pm 0.07 (3)	0.79 \pm 0.07 (3)	0.81 \pm 0.12 (3)

the winter data set failed the Durbin-Watson test due to autocorrelation, RIA was used to confirm the BACI results. The high variability in between site differences (Fig. 2.8) accounted for the high minimum detectable difference in biovolume (Table 2.7). Power curves indicated that biovolume was the least powerful of the biological parameters for both the summer and winter data sets (Figure 2.2E).

F. Patterns of Species Diversity and Species Evenness

The pattern in the Shannon Wiener diversity index (H') and the evenness index (J') over the entire period from 1983 to 1991 (Figs. 2.9 and 2.10, Tables 2.16 and 2.17) was similar, with evenness and diversity appearing to track each other during most seasons. In general, the pattern for both indices was that greatest values occurred in the winter months and lowest values in the summer months. This pattern continued for the 1989-1991 period.

The pattern of winter highs and summer lows for diversity and evenness corresponded with predictable patterns in species abundance. During the summers from 1983 to 1991, only Achnanthes minutissima and Cocconeis placentula ever achieved dominance greater than 10 % of the individuals in the community (Table 2.18). Typically, Achnanthes was the most dominant species present in May and June, but decreased in abundance and was replaced by Cocconeis as the most dominant species in July and August. Achnanthes then increased in dominance again in September and October as the abundance of Cocconeis declined. In 1991, Cocconeis abundances followed a similar pattern, reaching its highest levels (55-60% during the summer period) since the start of the study (Fig. 2.11, 2.12). This general pattern was based on total numbers of diatoms present. Since Cocconeis is more than 1.5 times larger than Achnanthes, the pattern of July-August dominance by Cocconeis is actually under-represented by data based on counts. From examination of shards of the actual sample slide under the scanning electron microscope, it appears that Cocconeis totally dominates the substrate surface with Achnanthes cells interspersed in spaces between the almost continuous covering of the microscope slide by Cocconeis. Thus, calculation of % dominance based on biovolume might be a better way of assessing dominance and is a calculation we hope to include in future reports.

The abundance data from the summer of 1989 was different from data collected for previous summers in that Fragilaria vaucheriae achieved greater than 10 % dominance along with Achnanthes minutissima and Cocconeis placentula. This unusual dominance pattern for Fragilaria can be explained by

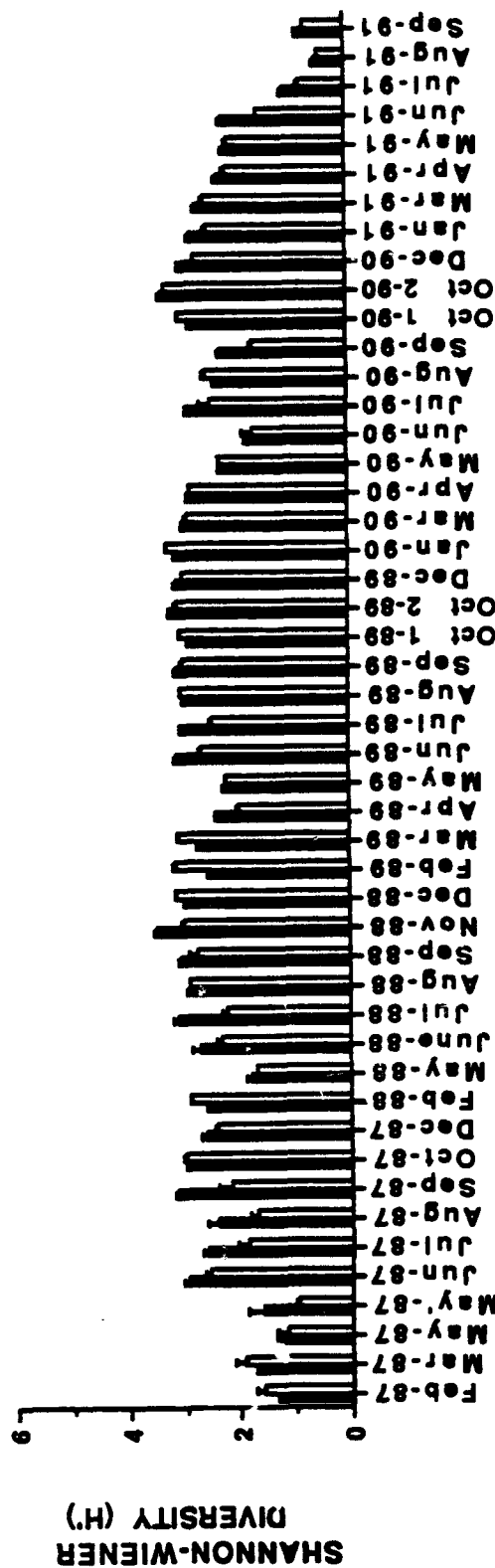
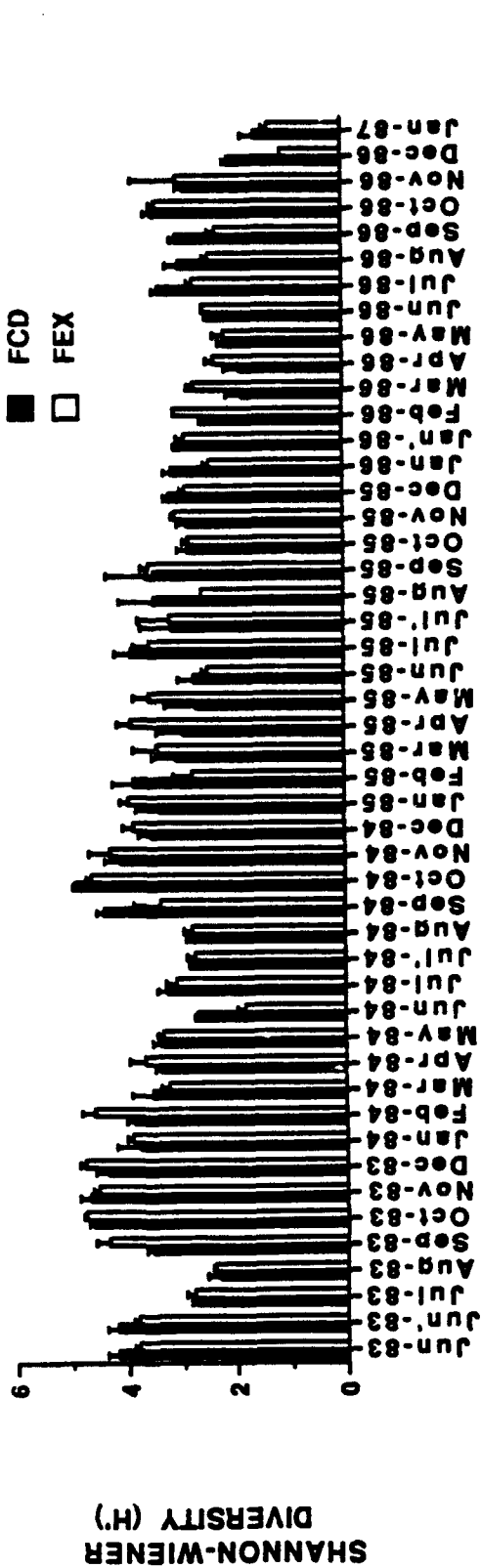


FIGURE 2.9 DIATOM SPECIES DIVERSITY FOR THE FORD RIVER, 1983-1991.

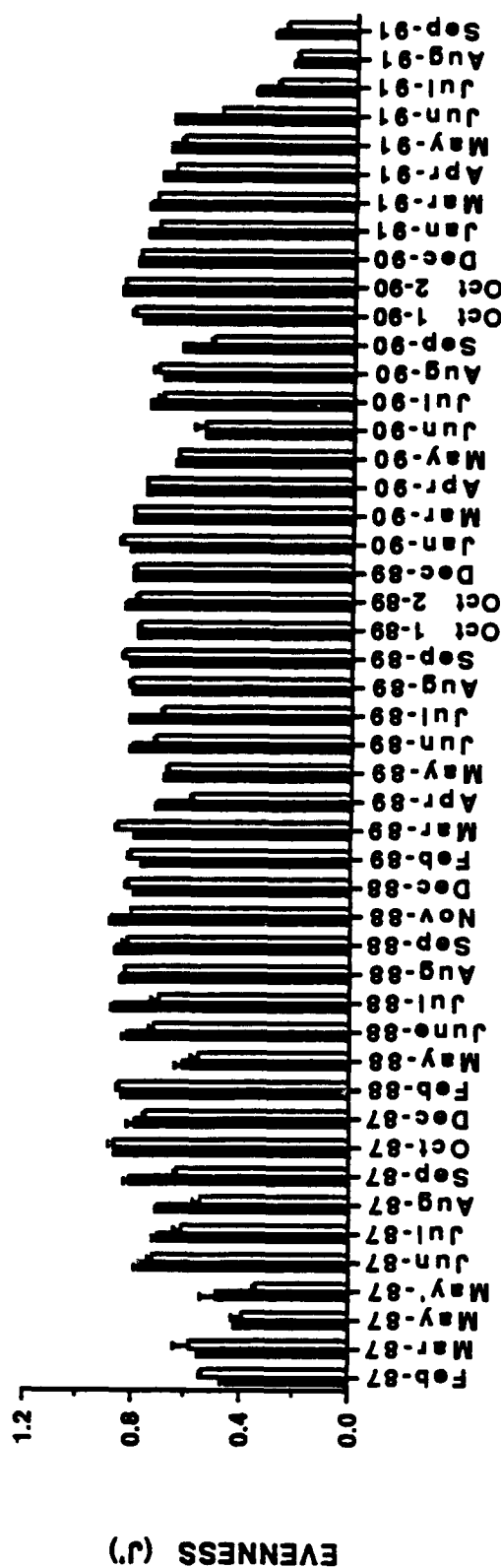
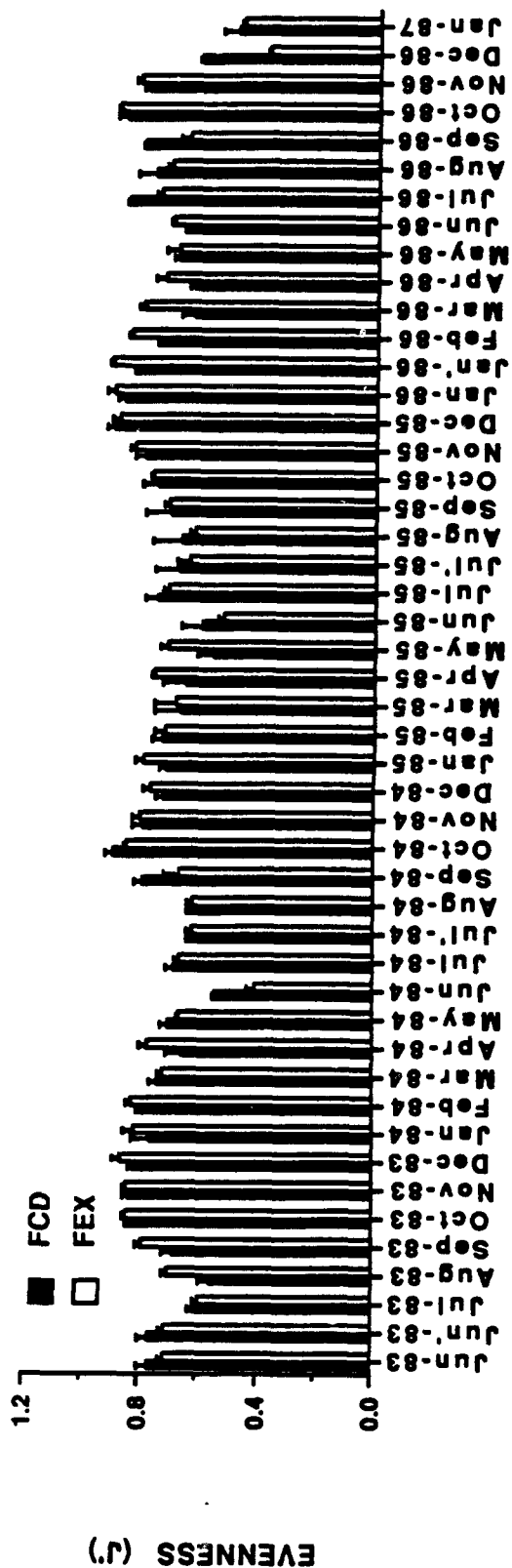


FIGURE 2.10 DIATOM SPECIES EVENNESS FOR THE FORD RIVER, 1983-1991.

Table 2.16 Species Diversity (H') for Experimental (FEX and FEX-N) and Control (FCD and FCD-N) sites for 1990-1991. Values are Means \pm S.E, N in parentheses.

Date	Experimental		Control	
	FEX	FEX-N	FCD	FCD-N
6/11/90	---	1.674 \pm 0.189 (3)	1.817 \pm 0.026 (3)	1.787 \pm 0.052 (3)
7/9/90	---	2.447 \pm 0.212 (2)	2.867 \pm 0.022 (2)	3.082 \pm 0.034 (2)
8/6/90	2.547 \pm 0.024 (3)	1.693 \pm 0.003 (3)	2.400 \pm 0.022 (3)	2.354 \pm 0.082 (3)
9/4/90	1.678 \pm 0.027 (3)	1.448 \pm 0.039 (3)	2.251 \pm 0.036 (3)	2.290 \pm 0.019 (3)
10/1/90	3.004 \pm 0.030 (3)	2.634 \pm 0.017 (3)	2.814 \pm 0.025 (3)	2.973 \pm 0.028 (3)
10/29/90	3.244 \pm 0.040 (3)	3.262 \pm 0.039 (3)	3.334 \pm 0.026 (3)	3.115 \pm 0.036 (3)
12/10/90	2.735 \pm 0.013 (6)	2.993 \pm 0.018 (6)	3.010 \pm 0.020 (6)	3.044 \pm 0.017 (6)
1/19/91	2.516 \pm 0.014 (6)	2.842 \pm 0.018 (6)	2.794 \pm 0.022 (6)	3.098 \pm 0.023 (6)
3/2/91	2.566 \pm 0.032 (6)	2.707 \pm 0.022 (6)	2.702 \pm 0.020 (6)	3.028 \pm 0.028 (6)
4/22/91	2.177 \pm 0.034 (6)	2.040 \pm 0.014 (6)	2.327 \pm 0.020 (6)	2.259 \pm 0.024 (6)
5/20/91	2.122 \pm 0.021 (3)	2.309 \pm 0.019 (3)	2.165 \pm 0.024 (3)	2.138 \pm 0.050 (3)
6/17/91	1.572 \pm 0.031 (3)	1.781 \pm 0.016 (3)	2.203 \pm 0.038 (3)	1.752 \pm 0.016 (3)
7/15/91	0.823 \pm 0.039 (3)	0.629 \pm 0.034 (3)	1.105 \pm 0.035 (3)	0.851 \pm 0.026 (3)
8/12/91	0.464 \pm 0.032 (3)	0.533 \pm 0.023 (3)	0.527 \pm 0.054 (3)	0.725 \pm 0.053 (3)
9/9/91	0.706 \pm 0.017 (3)	0.774 \pm 0.015 (3)	0.861 \pm 0.019 (3)	0.585 \pm 0.053 (3)

Table 2.17 Species Evenness (J') for Experimental (FEX and FEX-N) and Control (FCD and FCD-N) sites for 1990-1991. Values are Means \pm S.E, N in parentheses.

Date	Experimental		Control	
	FEX	FEX-N	FCD	FCD-N
6/11/90	---	0.549 \pm 0.040 (3)	0.538 \pm 0.010 (3)	0.542 \pm 0.013 (3)
7/9/90	---	0.700 \pm 0.022 (2)	0.749 \pm 0.006 (2)	0.814 \pm 0.004 (2)
8/6/90	0.720 \pm 0.024 (3)	0.550 \pm 0.004 (3)	0.700 \pm 0.005 (3)	0.660 \pm 0.016 (3)
9/4/90	0.519 \pm 0.008 (3)	0.438 \pm 0.012 (3)	0.634 \pm 0.002 (3)	0.650 \pm 0.008 (3)
10/1/90	0.813 \pm 0.006 (3)	0.765 \pm 0.010 (3)	0.772 \pm 0.006 (3)	0.777 \pm 0.006 (3)
10/29/90	0.844 \pm 0.009 (3)	0.844 \pm 0.009 (3)	0.857 \pm 0.005 (3)	0.828 \pm 0.007 (3)
12/10/90	0.789 \pm 0.006 (6)	0.791 \pm 0.005 (6)	0.800 \pm 0.004 (6)	0.795 \pm 0.004 (6)
1/19/91	0.721 \pm 0.002 (6)	0.784 \pm 0.004 (6)	0.758 \pm 0.005 (6)	0.825 \pm 0.007 (6)
3/2/91	0.727 \pm 0.009 (6)	0.771 \pm 0.007 (6)	0.755 \pm 0.003 (6)	0.815 \pm 0.004 (6)
4/22/91	0.660 \pm 0.007 (6)	0.672 \pm 0.004 (6)	0.709 \pm 0.005 (6)	0.661 \pm 0.008 (6)
5/20/91	0.639 \pm 0.008 (3)	0.664 \pm 0.009 (3)	0.679 \pm 0.008 (3)	0.613 \pm 0.012 (3)
6/17/91	0.493 \pm 0.008 (3)	0.598 \pm 0.003 (3)	0.677 \pm 0.001 (3)	0.566 \pm 0.003 (3)
7/15/91	0.281 \pm 0.014 (3)	0.234 \pm 0.012 (3)	0.359 \pm 0.013 (3)	0.271 \pm 0.010 (3)
8/12/91	0.217 \pm 0.008 (3)	0.210 \pm 0.007 (3)	0.210 \pm 0.023 (3)	0.263 \pm 0.018 (3)
9/9/91	0.258 \pm 0.005 (3)	0.337 \pm 0.009 (3)	0.296 \pm 0.005 (3)	0.232 \pm 0.025 (3)

Table 2.18 Dominant Summer Diatom Species at Experimental (FEX) and Control (FCD) Sites, 1983-1991. Values for each species indicate percent dominance by numbers.

Site		<i>Achnanthes minutissima</i>	<i>Cocconeis placentula</i>	<i>Diatoma tenue</i>	<i>Fragilaria vaucheriae</i>	<i>Gomphonema intricatum</i>	<i>Gomphonema olivaceum</i>	<i>Meridion circulare</i>	<i>Navicula cryptocephala</i>	<i>Synedra ulna</i>
FEX	83	15	34							
	84	40	27							
	85	32	31							
	86	31	20							
	87	30	19							
	88	24	25							
	89	19	15		10					
	90	35	12							
	91	21	60							
FCD	83	14	39							
	84	34	21							
	85	32	24							
	86	22	9							
	87	24	20							
	88	22	14							
	89	16	15		12					
	90	29	15							
	91	19	55							

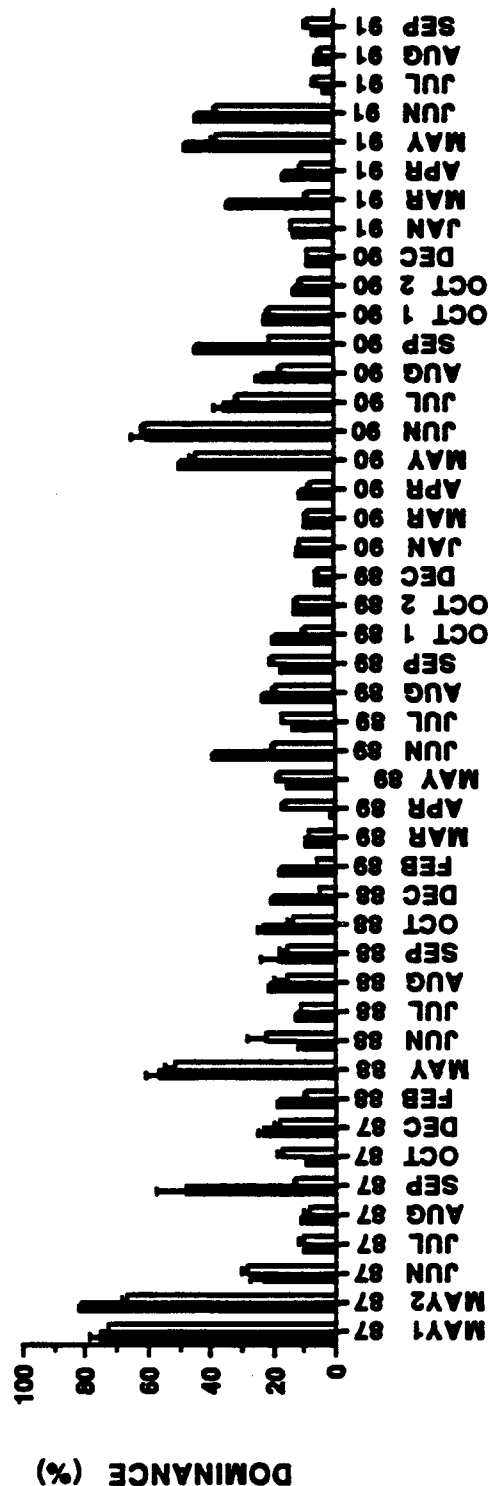
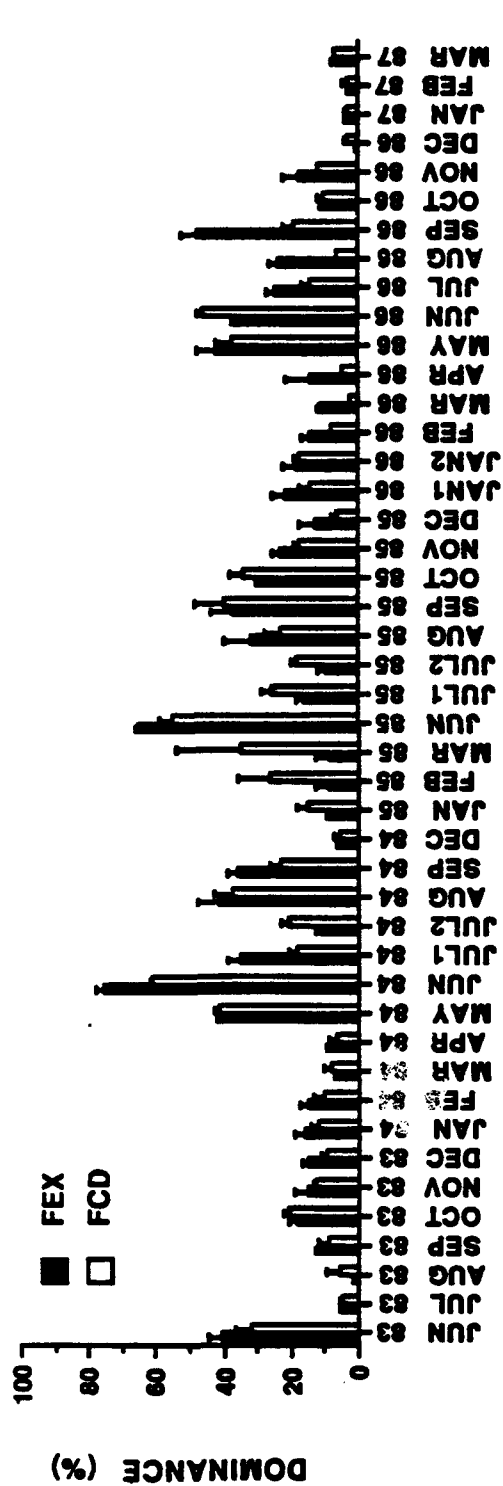


FIGURE 2.11 Achnanthes minutissima PERCENT DOMINANCE FOR THE FORD RIVER, 1983-1991.

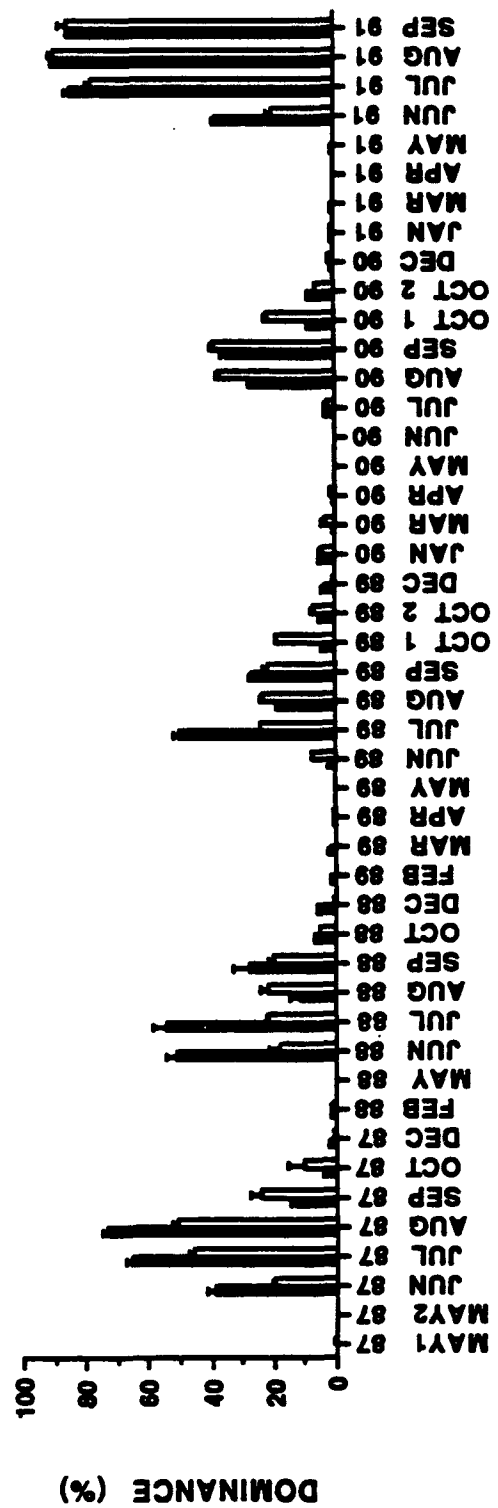
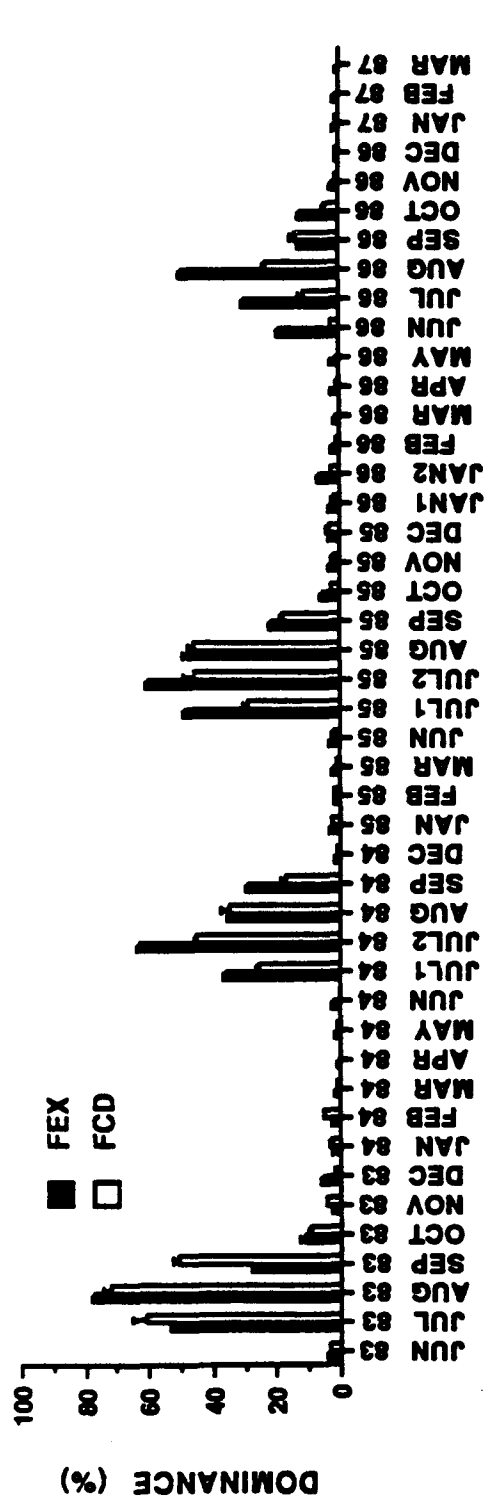


FIGURE 2.12 Cocconeis placentula PERCENT DOMINANCE FOR THE FORD RIVER, 1983-1991.

its unusually high abundance (40 % dominance) during the month of May, 1989. During 1991, Fragilaria abundance appeared to follow the more typical pattern seen from 1983-1988 (Fig. 2.13).

The winter diatom flora has been much more variable than the summer flora. Achnanthes has been a dominant component of the flora most years, as well as Fragilaria vaucheriae and Gomphonema olivaceum (Table 2.19). The winter of 1990-1991 followed this dominance pattern, with the reappearance of Gomphonema as a dominant species (Table 2.19, Fig. 2.14). Synedra ulna, which became a dominant species during the unusually warm winter of 1986-87 when it reached abundance levels of 51%, was not a dominant member of the winter community during 1990 (Table 2.19, Fig. 2.15). The variable winter species abundance pattern observed during 1990 resulted in typical patterns of high diversity and evenness seen in previous winters.

Non-dominant (< 10% of total community composition) species such as Achnanthes lanceolata, Cymbella minuta, Fragilaria construens and Synedra ulna have also responded in a predictable manner throughout the eight year period (Figs. 2.16, 2.17, 2.18, 2.15). These species can also be divided into species that achieve greatest dominance in winter or summer. Species that are most abundant in summer include only Cymbella minuta (Fig. 2.17). There are three winter abundant species: Achnanthes lanceolata, Fragilaria construens and Synedra ulna (Figs. 2.16, 2.18, 2.15). The combination of more dominant forms in the winter as well as the preponderance of minor species with peak abundance in the winter leads to the observed pattern in diversity and evenness of winter highs and summer lows (Figs. 2.9, 2.10).

We have quantified the changes in diatom abundance over time by analyzing dominant species present in winter and summer and several non-dominant species with the BACI technique (Table 2.20). Differences between the control and impact sites were calculated using the arcsin square root of the mean transformation suggested by Steel and Torrie (1960) for proportional data. There have been no significant changes in the inter-site relationships since the ELF antenna became fully operational in October of 1989 for any of the dominant summer (Achnanthes, Cocconeis) or winter species (Achnanthes, Fragilaria, Gomphonema) when the entire seasonal 1983-1985 "before" data were compared to the 1989-1991 "after" data (Table 2.20). Seasonal pooled BACI comparisons of mean differences for the typically non-dominant species Cymbella minuta and Synedra ulna were also not significant (Table 2.20).

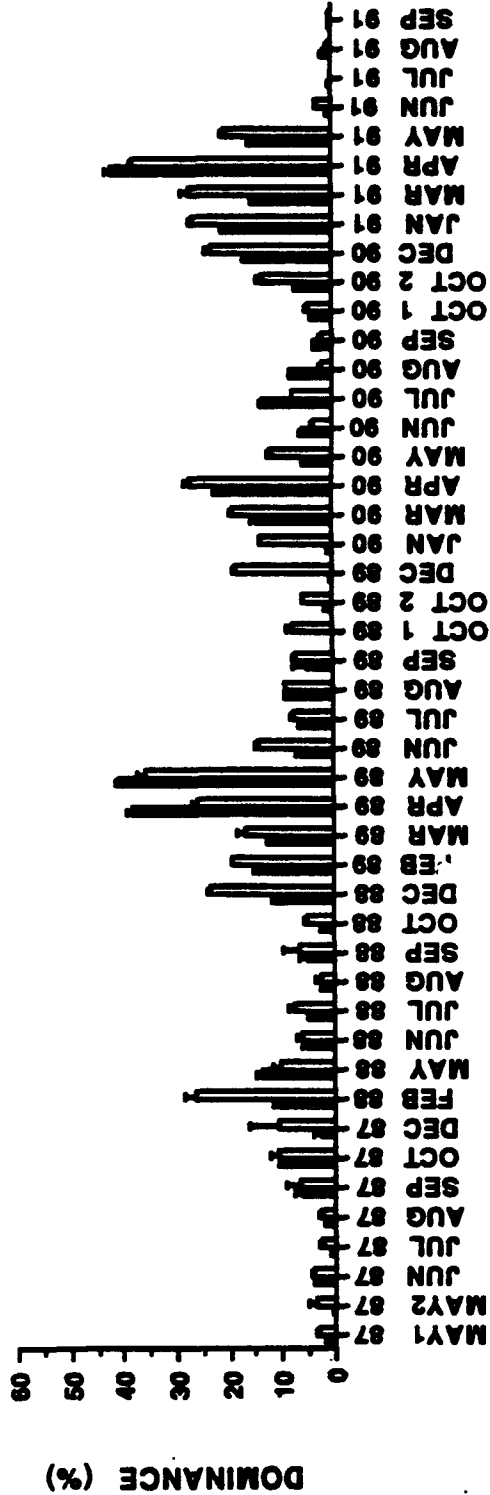
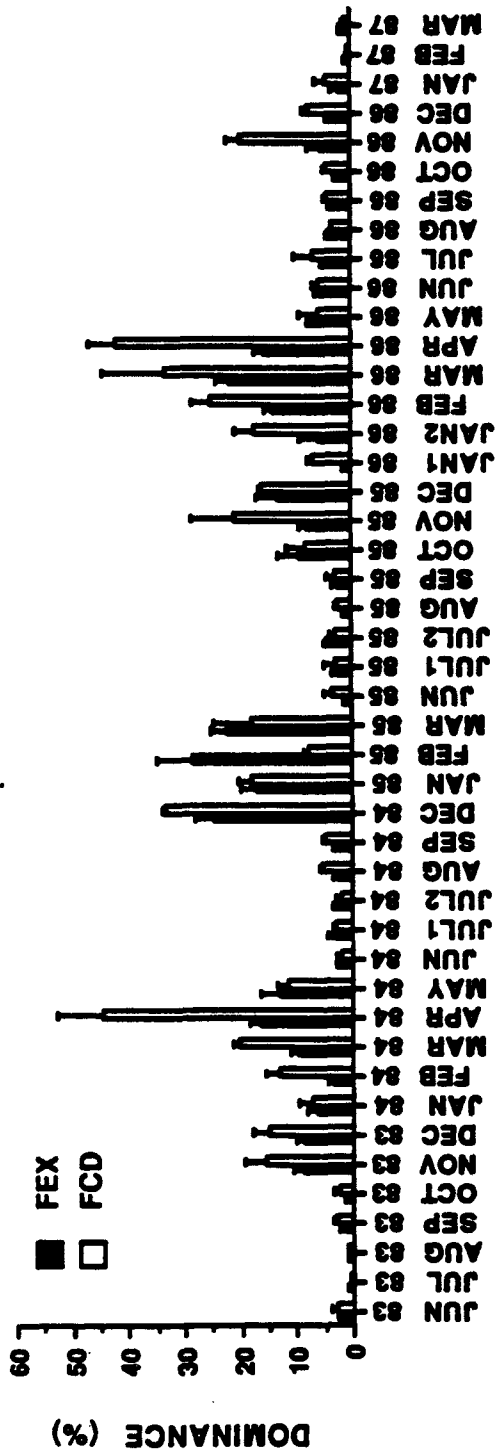


FIGURE 2.13 *Fragilaria vaucheriae* PERCENT DOMINANCE FOR THE FORD RIVER, 1983-1991.

Table 2.19 Dominant Winter Diatom Species at Experimental (FEX) and Control (FCD) Sites, 1983-1991. Values for each species indicate percent dominance by numbers.

Site		<i>Achnanthes minutissima</i>	<i>Cocconeis placentula</i>	<i>Diatoma tenue</i>	<i>Fragilaria vaucheriae</i>	<i>Gomphonema intricatum</i>	<i>Gomphonema olivaceum</i>	<i>Meridion circulare</i>	<i>Navicula cryptocephala</i>	<i>Synedra ulna</i>
FEX										
	83	13		9		14	10			
	84	8		23		23				
	85	16		11		4	8			
	86		10							53
	87	21		6	12	8		12		
	88	12		19		3				
	89	9		9						13
	90	18		23		13				
FCD										
	83	10		19		11	13			
	84	21		12		21				
	85	10		23		11	11			
	86		8							50
	87	13		16	6	14		6		
	88	9		21		15				
	89	8		19						10
	90	10		27		5				

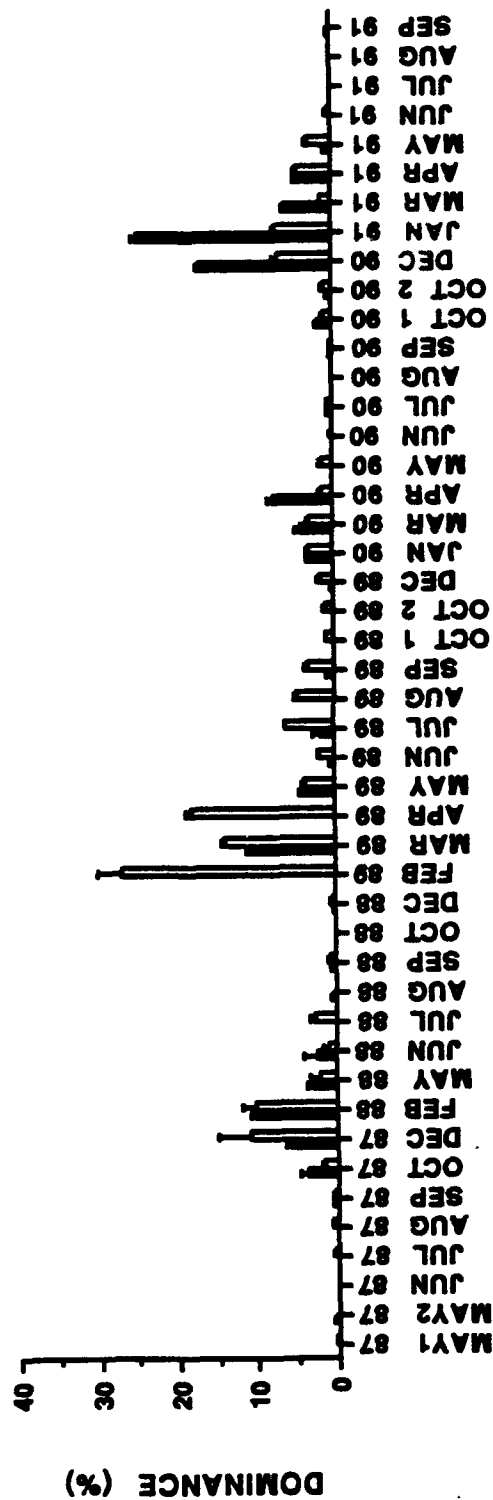
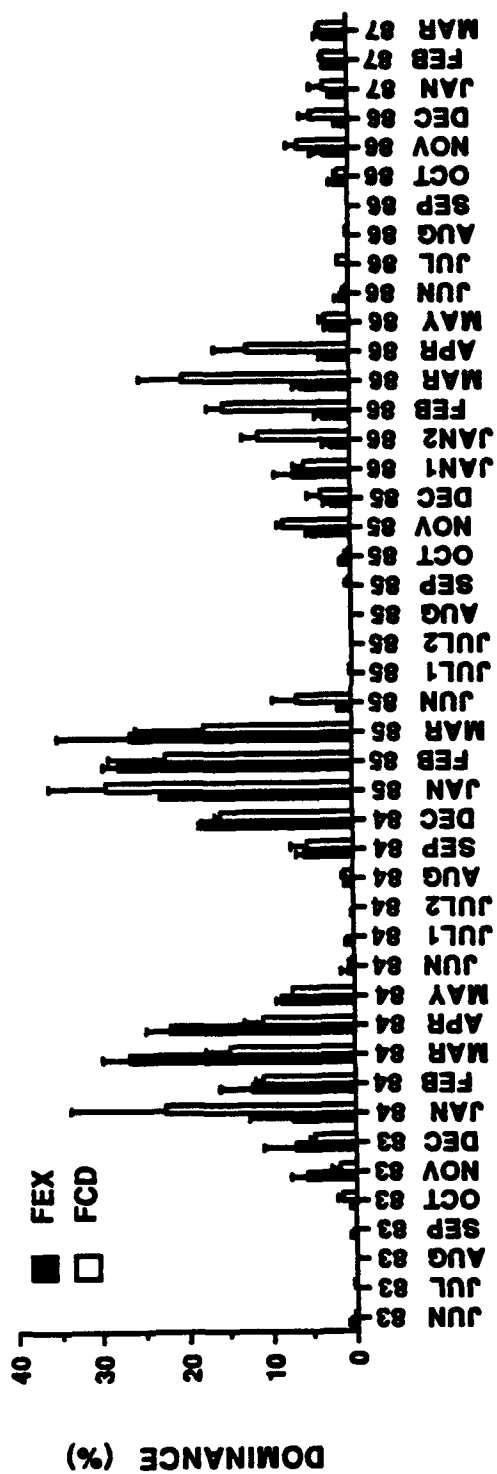


FIGURE 2.14 Gomphonema olivaceum PERCENT DOMINANCE FOR THE FORD RIVER, 1983-1991.

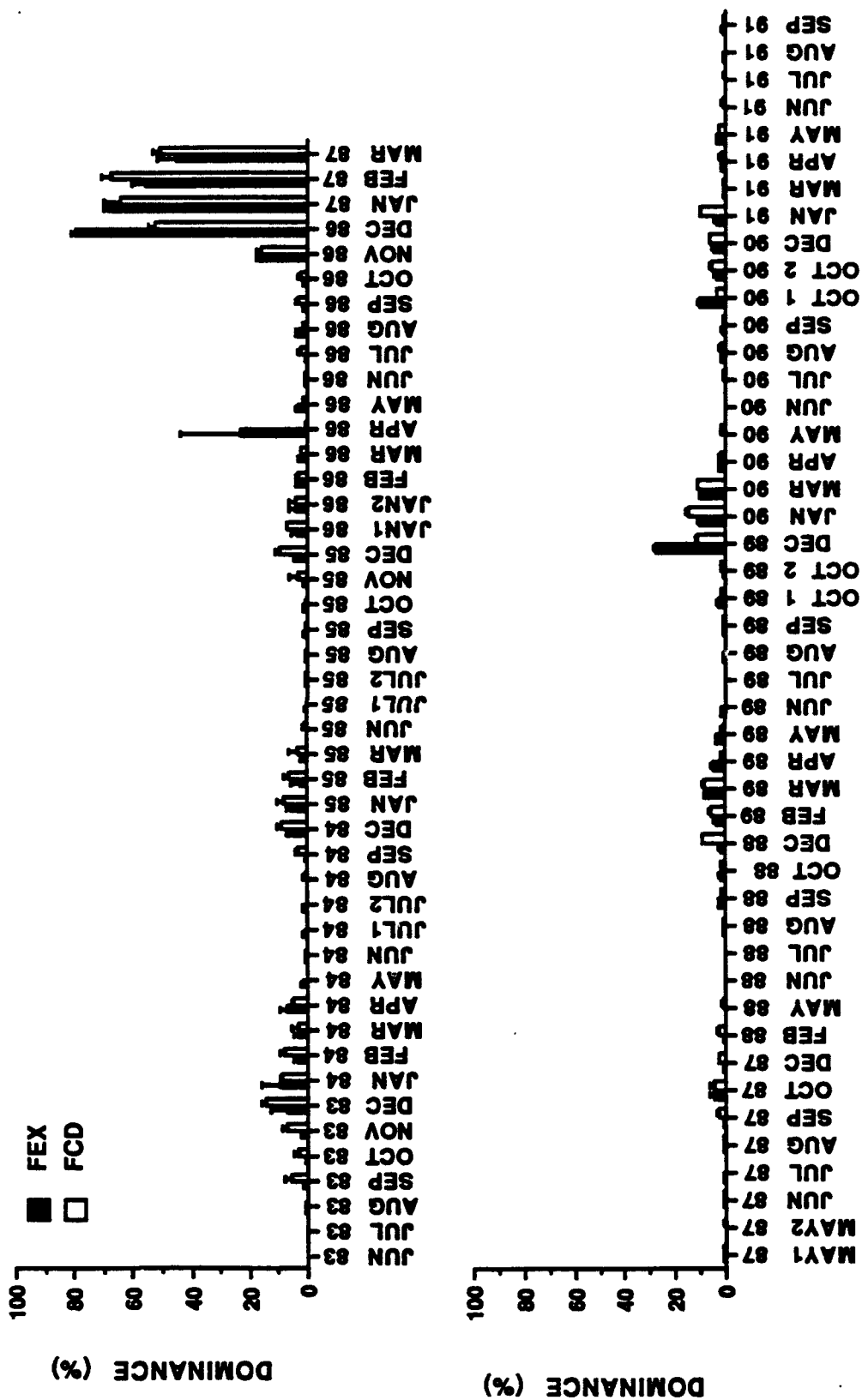


FIGURE 2.15 *Synedra ulna* PERCENT DOMINANCE FOR THE FORD RIVER, 1983-1991.

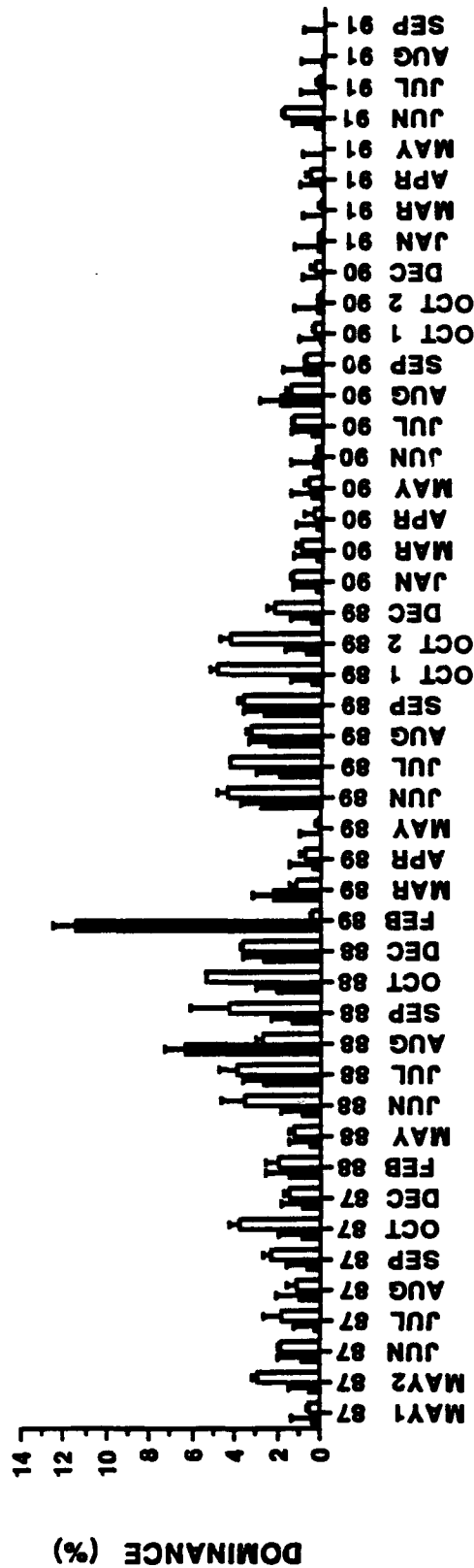
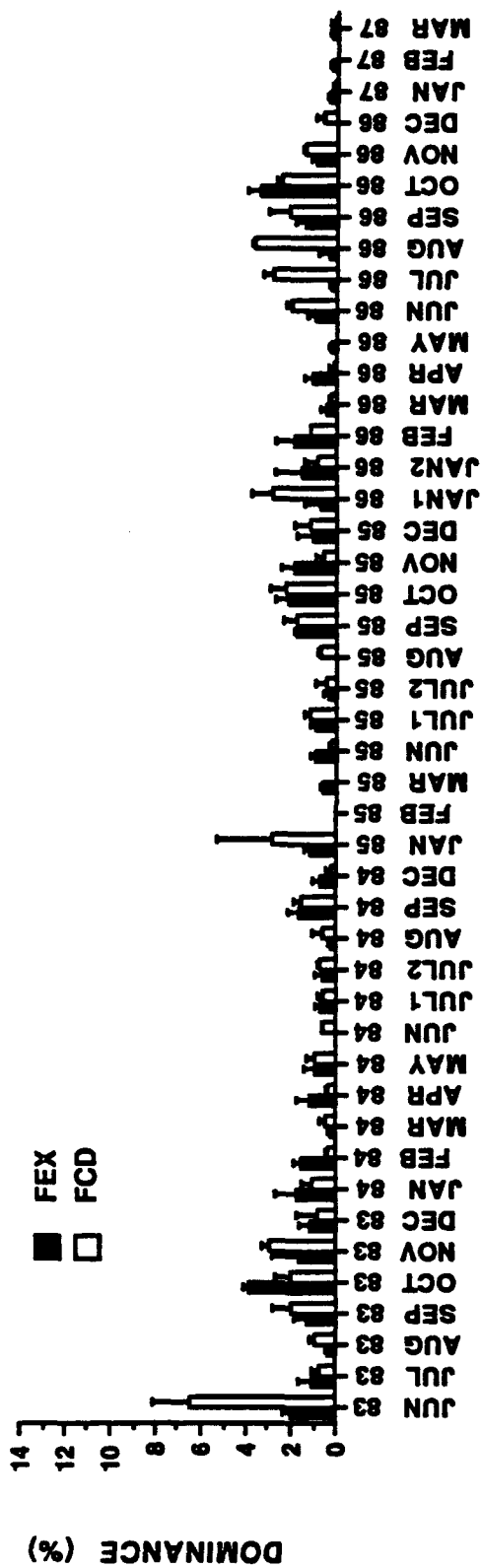


FIGURE 2.16 Achnanthes lanceolata PERCENT DOMINANCE FOR THE FORD RIVER, 1983-1991.

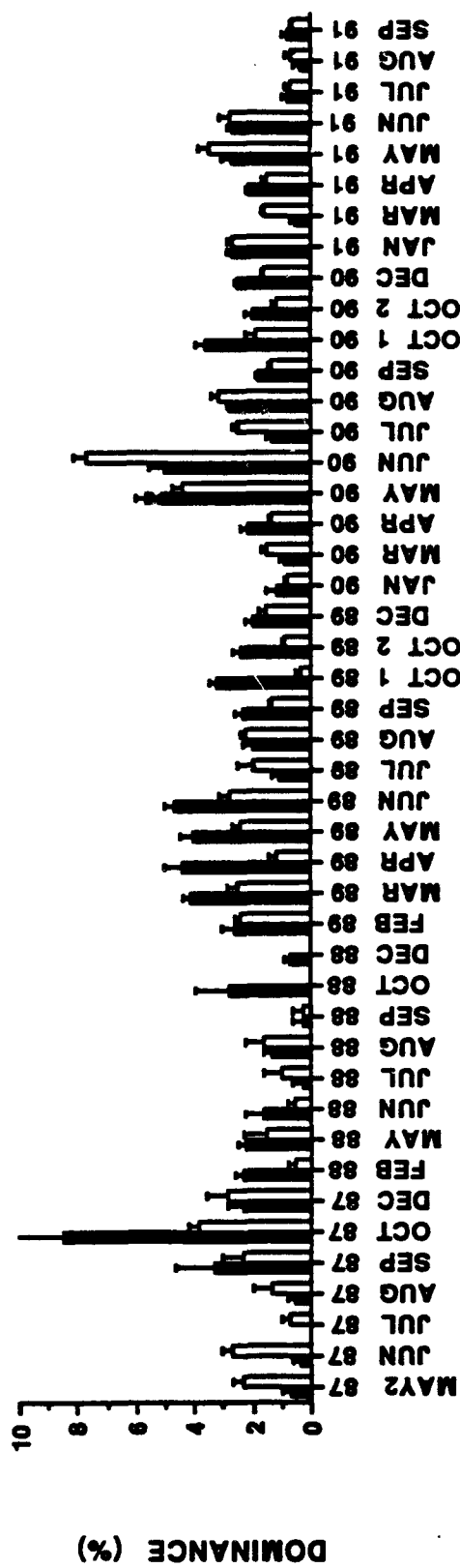
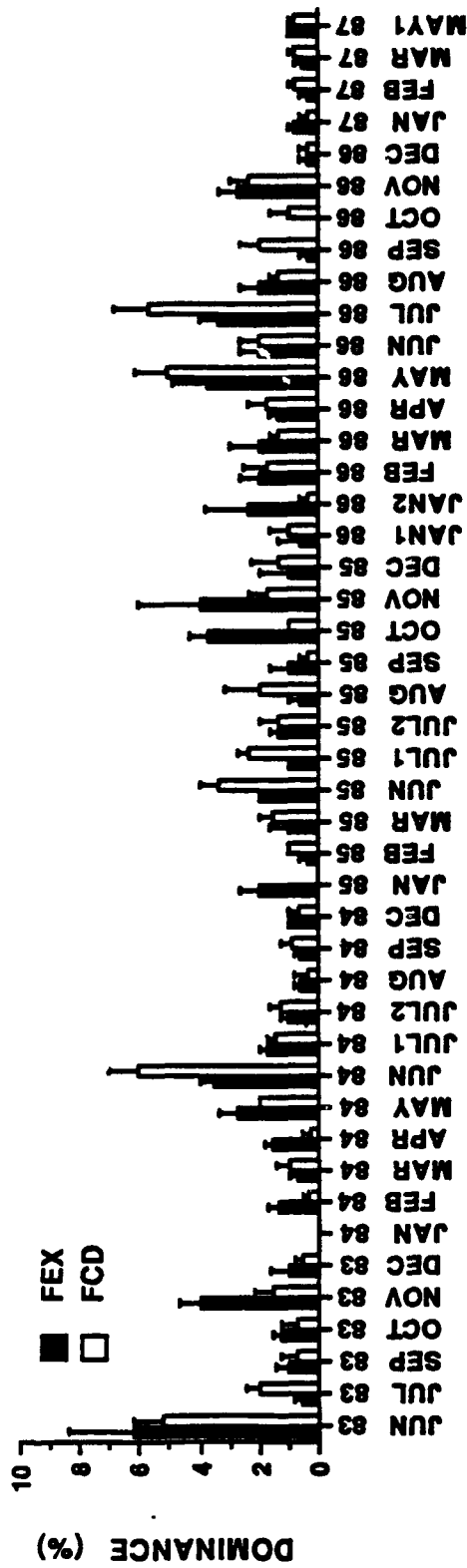


FIGURE 2.17 *Cymbella minuta* PERCENT DOMINANCE FOR THE FORD RIVER, 1983-1991.

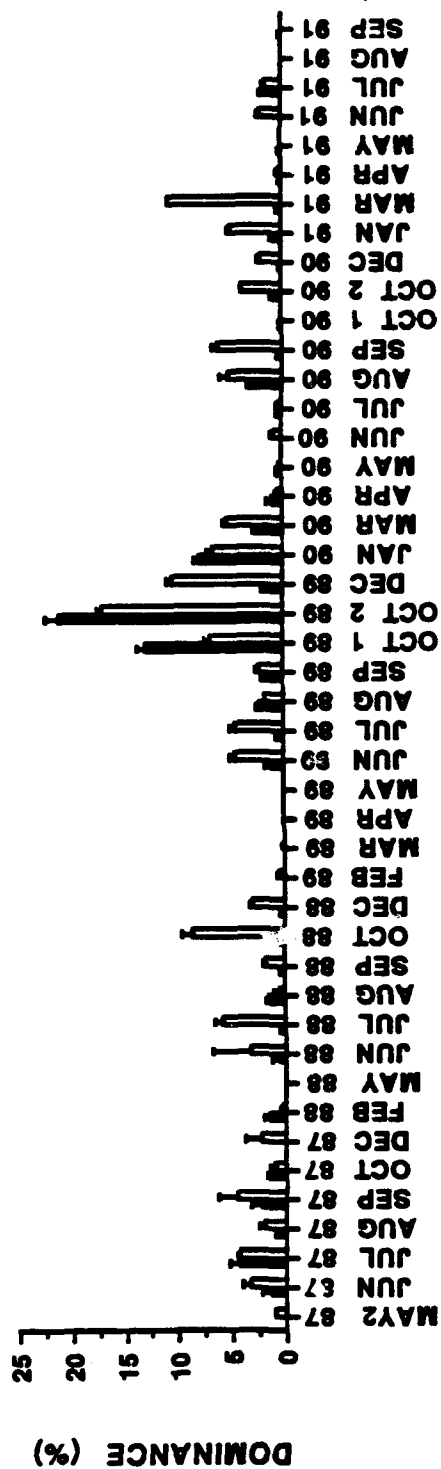
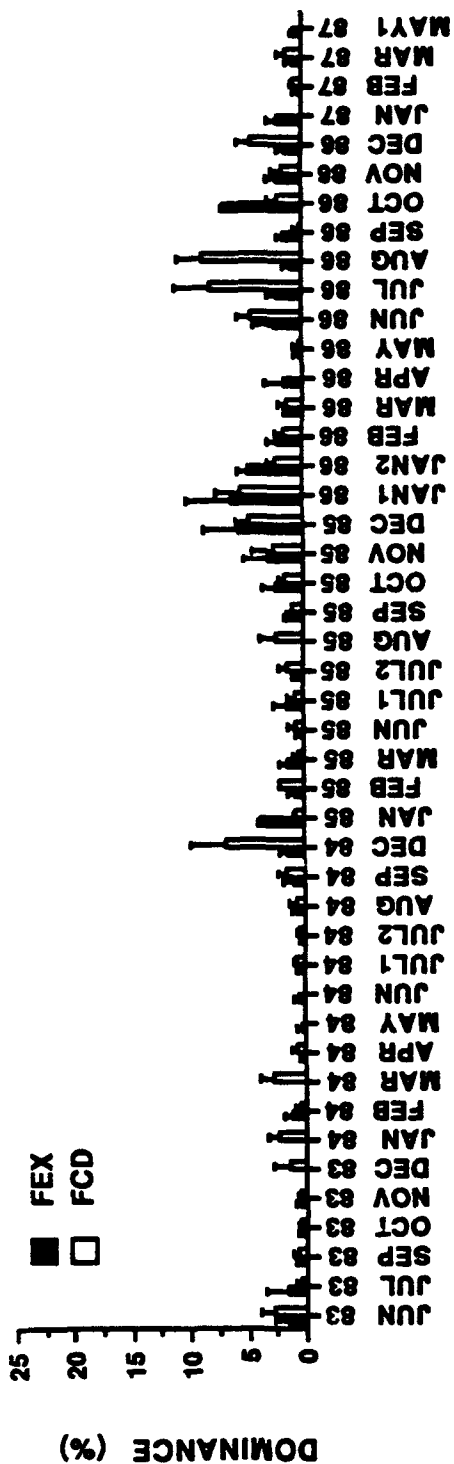


FIGURE 2.18 *Fragilaria construens* PERCENT DOMINANCE FOR THE FORD RIVER, 1983-1991.

Table 2.20 Summary of Diatom Abundance BACI and RIA Comparisons between Control (FCD) and Experimental (FEX) Sites for 1983-1991.

Species	Comparison	BACI Signif. (p < 0.05)	RIA Signif. (p < 0.05)
<u>Summer</u>			
Achnanthes minutissima	Summer 83-85 vs. 90-91	NS	
Cocconeis placentula	Summer 83-85 vs. 90-91	NS	
Cymbella minuta	Summer 83-85 vs. 90-91	NS	
<u>Winter</u>			
Achnanthes minutissima	Winter 83-86 vs. 89-90	NS	NS
Fragilaria vaucheriae	Winter 83-86 vs. 89-90	NS	NS
Gomphonema olivaceum	Winter 83-86 vs. 89-90	NS	NS
Synedra ulna	Winter 83-86 vs. 89-90	NS	NS

Last year we expanded our diatom abundance analyses to include RIA, as well as BACI. This year, RIA was run in addition to BACI for the winter data sets since these data exhibited significant autocorrelations or indecisive results for the Durbin-Watson test. RIA comparisons of abundance data for the five winter species indicated no significant differences in the between site relationship "before" and "after" antenna operation (Table 2.20). In all comparisons, results determined using RIA reflected results obtained by the BACI technique.

In an attempt to detect even more subtle changes in diatom abundances due to ELF exposure, we have run BACI analyses for dominant species that demonstrated obvious peaks in abundance during particular months of the year. For example, Achnanthes minutissima becomes very abundant during the months of May and June each year (Fig. 2.11). By pooling all the May and June data for the years 1983-85 as the "before" period and all the May and June data for 1989-91 as the "after", we can more closely examine mean differences between sites. We found no overall significant differences between mean percent dominance data for the four species analyzed using BACI (Table 2.21). With the addition of several more years of data, the analysis of these species may prove to be sensitive indicators of potential ELF effects.

Comparisons of diversity and evenness between FEX and FCD using paired t-tests indicated that a significant difference occurred between sites for the June, 1990-September, 1991 data set (Table 2.2) and for the entire data set from 1983-1991 (Table 2.6). Correlation coefficients of 0.97 for diversity and 0.96 for evenness indicated the close relationship of these parameters between FEX and FCD for 1990-1991 (Table 2.2). These relationships remained highly correlated when data from 1983-1991 were considered (Table 2.6).

Each of the new sites, FEX-N and FCD-N, did not differ significantly for both diversity and evenness from FEX and FCD, respectively (Tables 2.3 and 2.4). Significant correlation coefficients between FEX-N and FEX, and between FCD-N and FCD were found for both parameters. When the site of highest exposure (FEX-N) was compared to the site of lowest exposure (FCD-N) for the June, 1990-September, 1991 period, only species diversity was found to differ significantly (Table 2.5).

Both evenness and diversity exhibit low minimum detectable differences, 5.1% and 7.4%, respectively (Table 2.7). Additionally, power analyses completed for each parameter indicated that both diversity and evenness

Table 2.21 Results of Monthly BACI Comparisons of Dominant Diatom Species, 1983-1991.
Degrees of freedom in parentheses.

Species	Comparison	BACI Significance (NS = $p > 0.05$)
<i>Achnanthes minutissima</i>	May & Jun 83-85 vs. May & Jun 90-91 (6)	NS
<i>Cocconeis placentula</i>	Jul & Aug 83-85 vs. Jul & Aug 90-91 (10)	NS
<i>Fragilaria vaucheriae</i>	Feb, Mar, Apr 83-86 vs. Feb, Mar, Apr 89-90 (10)	NS
<i>Gomphonema olivaceum</i>	Feb & Mar 83-86 vs. Feb & Mar 89-90 (6)	NS

represent the best means of detecting potential ELF effects (Fig. 2.2F, 2.2G).

Results of BACI comparisons for diversity indicated that no significant changes occurred in the inter-site relationship for the pooled "before" (6/83-4/86) and "after" (10/89-9/91) data (Table 2.13). Seasonal pooled comparisons for diversity were not significant. The entire evenness data set was analyzed using both the BACI analysis and RIA. A significant difference in the between site relationship for evenness occurred for the overall comparison using both statistical techniques (Table 2.13). The winter evenness comparison was also found to differ significantly at the $p < 0.01$ level using both BACI and RIA (Table 2.13).

G. Photosynthesis-Respiration Studies

A separate study was undertaken to evaluate primary production and community respiration using short term changes in dissolved oxygen concentrations during the summer period of intense algal growth. The dissolved gas procedures are advantageous because estimates of net primary production, gross primary production, and community respiration may be obtained with one technique (Bott *et al.* 1979). Rocks from the stream bed were placed inside each of six plexiglass chambers occupying 1/3 to 1/4 of the total chamber volume of 3-4 L. Three light and three dark chambers were run simultaneously on each date. Recirculated water was continuously recycled through the chambers using submersible pumps. Each test lasted from 0.5-2.0 hours between 1000 and 1300 hours of each test day in 1984. One site was tested during one week, and the second was tested during the following week in 1984. Even though 1984 results indicated no significant difference (t-test) between sites for net production, respiration, or gross production, the relatively large standard deviations led us to change procedures concerning exposure durations and site selection for 1985. Since 1985, production and respiration studies at FCD and FEX have been conducted on the same day with the test at each site lasting one hour. Tests were begun at one site at 1000 hours and completed at the other site by 1400 hours. Each site was tested first on alternate weeks.

The assumptions made for the purposes of production calculations considered algal periphyton to occupy only the upper half of each rock. Chlorophyll *a*, extracted from rocks covered by attached periphyton, was measured for each chamber with a fluorimeter. Surface area was determined by wrapping each rock in aluminum foil, straightening the foil, and

determining the area of foil using a leaf area meter (LI-COR). Hourly production and respiration rates were estimated (Table 2.22) from dissolved oxygen, chlorophyll *a*, and rock surface area measurements.

We agree with reviewers from past years that production and respiration studies should be done for as many seasons of the year as possible. However, these procedures are labor intensive (ca. 40-50 hours per determination or 400 to 500 hours for the 10 runs per summer) and can only be done with present level of funding during times when student technicians are available (June 15 through September 1). Thus, these determinations will be done in this period only unless additional funds are forthcoming for studies during other seasons. We also agree that ¹⁴C studies would be better than just monitoring changes in dissolved oxygen. Again, lack of equipment and funding to purchase such equipment precludes this as well.

Gross and net primary production and respiration were similar between the control (FCD) and experimental (FEX) sites for 1991 (Table 2.22). We have analyzed gross primary production rates from 1984 to 1991 with the BACI technique (Table 2.13). There was no significant difference in the between site relationship for the pooled "before" and "after" data.

H. BACI and RIA Comparisons of Biological and Diatom Abundance Data

Results obtained last year using the RIA method generally reflected those from BACI. Similar probability levels were found for AFDW-biomass, AFDW-biomass accrual, cell volume, diversity, evenness, gross primary production and seasonal diatom abundance data. While probability levels did not agree precisely between methods for parameters such as chlorophyll *a*, chlorophyll *a* accrual, cell density and biovolume, the *p* values were usually within a few percentage points of one another. Based on reviewers comments of last year's report, we have limited our use of the non-parametric RIA to those comparisons which failed the assumptions of the parametric BACI analysis, or significant comparisons obtained using BACI. Since the BACI analysis provides a statistically more powerful test of the benthic algal data, we have elected to use RIA only in the instances described above. Overall, we feel that RIA continues to offer a means of increasing the statistical rigor of this portion of the study.

For those parameters where significant differences did occur using both BACI and RIA, a closer look is required to

Table 2.22 Hourly Production and Respiration Rates for Rock Substrates of the Ford River.

Date	NET PRIMARY PRODUCTION			RESPIRATION*			GROSS PRIMARY PRODUCTION**		
	mgO ₂ /m ²	mg Chl a/m ²	mgO ₂ /mg Chl a	mgO ₂ /m ²	mg Chl a/m ²	mgO ₂ /mg Chl a	mgO ₂ /m ²	mgO ₂ /mg Chl a	mg Chl a
FORD CONTROL SITE (FCD)									
6/11/91	68.11 ± 10.74	36.91 ± 5.12	1.86 ± 0.17	26.49 ± 3.52	29.26 ± 4.31	0.99 ± 0.38	94.60		3.85
7/9/91	75.10 ± 16.11	30.88 ± 7.53	2.81 ± 1.11	17.98 ± 3.90	19.41 ± 1.82	0.94 ± 0.19	93.89		3.75
7/10/91	47.60 ± 10.51	21.13 ± 2.80	2.19 ± 0.24	29.45 ± 1.38	24.12 ± 1.63	1.24 ± 0.13	77.06		3.43
7/11/91	49.03 ± 6.62	14.18 ± 0.39	3.44 ± 0.37	20.43 ± 6.58	16.15 ± 5.16	1.40 ± 0.34	69.46		6.04
7/30/91	40.92 ± 7.29	20.79 ± 4.67	2.39 ± 0.93	21.03 ± 4.86	26.16 ± 3.77	0.80 ± 0.16	61.95		3.18
8/12/91	58.04 ± 10.14	34.59 ± 2.84	1.96 ± 0.45	37.16 ± 4.68	32.24 ± 2.85	1.17 ± 0.19	95.20		3.13
8/13/91	78.69 ± 20.54	30.91 ± 3.85	2.76 ± 0.89	48.65 ± 11.31	25.14 ± 4.16	1.98 ± 0.47	127.34		4.74
8/14/91	77.17 ± 26.25	20.92 ± 3.70	3.47 ± 0.81	39.66 ± 3.91	24.80 ± 5.56	1.72 ± 0.26	116.83		5.18
8/20/91	54.08 ± 12.93	24.43 ± 1.01	2.25 ± 0.61	41.00 ± 7.32	32.21 ± 3.24	1.34 ± 0.37	95.87		3.59
8/27/91	41.19 ± 15.07	17.41 ± 1.73	2.43 ± 1.02	48.27 ± 8.22	25.65 ± 1.97	1.95 ± 0.46	89.46		4.38
Ave ± S.E.	58.99 ± 4.66	25.22 ± 2.42	2.56 ± 0.18	33.01 ± 3.63	25.51 ± 1.60	1.35 ± 0.13	92.01 ± 6.27		3.91 ± 0.26
FORD EXPERIMENTAL SITE (FEX)									
6/11/91	33.53 ± 11.48	32.15 ± 1.89	1.09 ± 0.40	35.07 ± 9.92	28.24 ± 3.81	1.31 ± 0.16	69.40		2.40
7/9/91	64.22 ± 1.85	23.84 ± 3.55	2.82 ± 0.44	17.09 ± 0.81	19.45 ± 3.43	0.94 ± 0.18	81.31		3.76
7/10/91	59.99 ± 8.82	27.85 ± 5.38	2.29 ± 0.69	27.30 ± 6.29	25.83 ± 7.55	1.33 ± 0.51	87.30		3.62
7/11/91	74.18 ± 8.58	40.73 ± 16.89	2.33 ± 0.70	29.69 ± 3.74	37.59 ± 8.24	0.82 ± 0.09	103.86		3.15
7/30/91	62.10 ± 7.02	20.49 ± 3.78	3.15 ± 0.35	7.07 ± 2.02	17.66 ± 2.84	0.44 ± 0.18	69.17		3.59
8/12/91	35.89 ± 9.60	18.58 ± 3.62	1.90 ± 0.17	48.78 ± 5.86	14.35 ± 3.01	3.53 ± 0.38	84.67		5.43
8/13/91	76.28 ± 15.60	24.42 ± 0.60	3.10 ± 0.57	34.82 ± 14.47	17.84 ± 6.51	2.05 ± 0.64	111.09		5.16
8/14/91	39.99 ± 23.00	15.02 ± 6.82	2.93 ± 0.79	28.32 ± 6.65	19.76 ± 0.69	1.45 ± 0.37	68.31		4.38
8/20/91	62.28 ± 13.62	18.93 ± 3.34	3.45 ± 0.74	42.51 ± 11.70	15.45 ± 2.48	2.94 ± 0.85	104.80		6.39
8/27/91	47.70 ± 9.97	11.35 ± 3.01	4.97 ± 0.34	35.45 ± 5.21	15.78 ± 1.78	2.36 ± 0.53	83.14		7.33
Ave ± S.E.	55.82 ± 4.87	23.34 ± 2.72	2.80 ± 0.33	30.69 ± 13.79	21.20 ± 2.30	1.72 ± 0.31	86.30 ± 4.95		4.52 ± 0.49

* = Gross Respiration of Entire Microbial Community (Bacteria and Algae)

** = Total Metabolism = Respiration + Net Primary Production

determine whether ELF electromagnetic radiation or some other factors have caused the observed differences. Stewart-Oaten et al. (1986) and Carpenter (1989) both have strongly stated that significant differences obtained from RIA or BACI analyses do not imply that the perturbation in question has caused the observed differences, nor do these tests reveal at what point in time the change occurred. Throughout this study, we have limited our interpretation of significant BACI and RIA results to one which states that a significant difference ($p < 0.05$) in the inter-site relationship before and after antenna operation for a particular algal parameter, was or was not found. As Stewart-Oaten (1986), Carpenter (1989) and our reviewers have recommended, we have suggested pertinent ecological variables (water temperature and discharge) as alternate explanations in our attempt to separate natural variation from possible ELF effects. We agree with reviewers' comments that laboratory experiments would offer the only definitive means of determining whether ELF exposure is causing the observed statistical differences in the algal community, and are currently considering the feasibility of such experiments.

I. Summary

1. Chlorophyll a

Annual patterns for chlorophyll a standing crop and accrual were characterized by large year-to-year variability. The only consistent trend was for July-August peaks in most years and winter lows. The magnitudes of peaks also varied between years. Paired t-tests for 1990-91 data and all data collected since 1983 showed no significant difference between our control (FCD) and experimental sites (FEX). There was also no significant difference between the new FEX and FCD sites and the old FEX and FCD sites. "Before" (6/83-4/86) and "after" (10/89-9/91), control (FCD) and impact (FEX) (BACI) and Randomized Intervention Analysis (RIA) indicate that the between site relationship in chlorophyll a has changed since October, 1989 when the testing of the antenna began full operation.

2. Organic Matter

Organic matter (AFDW-biomass) standing crop and accrual rates showed considerable year-to-year variability similar to chlorophyll a. The only overall trend has been for a July-August peak in standing crop and accrual rates and winter time lows for both standing crop and accrual. These parameters have been consistently characterized by showing no significant differences between sites since 1983, although organic matter accrual at FEX was higher than FCD for 1990-

91. BACI analyses and RIA showed that a difference has occurred in AFDW-organic matter accumulation since the testing of the antenna began in 1986 and was due to differences between the summers of 1983-1985 (before years) and the summer of 1991 (after year). However, organic matter accrual rates showed no significant difference.

3. Diatom Cell Density

Diatom cell density was statistically different between FEX and FCD sites according to paired t-tests of data from 1990-1991 and 1983-1991. BACI analyses and RIA also indicated that data collected before May 1986 were significantly different from data collected after October 1989 due to summer variations. The increased density may be related to the low discharges and high temperatures during May and early summer in each of these years. Density was highest in May in both years.

4. Total Biovolume and Individual Cell Volume

Individual cell volume comparisons of diatoms between sites showed no significant differences between sites for 1990-1991 and 1983-1991 data according to paired t-tests. Biovolume at FEX and FCD was significantly different for the 1990-1991 data but not for the entire data set from 1983-1991. BACI analysis and RIA detected no significant changes in the inter-site relationship for cell volume but significant differences for biovolume as a result of summer variability. In general, average cell volume was high in winter and low in summer, whereas total biovolume tended to be highest in summer since it is the product of average volume times density.

5. Species Diversity and Evenness

Diatom species diversity and evenness were found to differ significantly between FEX and FCD in 1991 and for all data collected to date using paired t-tests. No differences were found between old and new sites for each parameter from 1990-1991. Only species diversity was found to differ significantly between FEX-N and FCD-N during 1990-1991. Annual trends showed a high diversity and evenness during winter (except winter of 1986-87) and lower values during the summer periods. In 1991, we calculated percent abundance for all species of diatoms and presented data for those species that achieved dominance greater than 10 % for any season. Two species, Achnanthes minutissima and Cocconeis placentula were found to dominate during the 1991 summer period. During

the 1991 summer, Cocconeis reached its highest abundances ever observed since 1983. Three species achieved dominance during the winter of 1989. BACI and RIA analyses were presented for four dominant and two non-dominant species of diatoms and showed that no significant differences have occurred before and after antenna operation began. Even so, overall diversity and evenness have changed significantly over that time period according to the paired t-tests, BACI, and RIA analyses.

6. Photosynthesis-Respiration Studies

Net primary production, respiration, and gross primary production of the community on rock surfaces did not differ greatly between sites. BACI analysis indicated that there have been no significant differences between FEX and FCD sites for gross primary production rates for "before" and "after" data.

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Element 3 - Effects of Insect Grazer Populations on
Periphyton communities.

Changes from workplan - This element was eliminated following the 1989 field season, since effects were determined to be too variable and inconsistent from year to year to be useful in detecting ELF effects. Efforts previously spent on this element were used for the periphyton studies at two additional sites for Element 2.

Element 4: Species Richness and Biomass of Stream Insects From Artificial Substrates in Riffles

Changes from Original Synopsis - A new site, FEX.LINE, 10 m downstream from the crossing of the E.L.F. line over the Ford River, was added in June, 1991, which is subject to higher E.L.F. exposure levels than the FEX experimental site. The original FEX site remains operational.

Objectives

1) To determine whether structural community parameters and functional community parameters are affected by E.L.F. electromagnetic fields, and 2) to determine whether growth rates six species of aquatic insects are altered after E.L.F. activation.

Rationale

Extremely low frequency electromagnetic fields may affect structural and functional community parameters (A.I.B.S. 1985) as well as life histories of insects (Walters and Carstensen 1986). Although a number of terrestrial animals, including insects (Bindokas et al. 1989, Kirschvink 1989) have been studied to see whether electromagnetic fields affect their behavior, no studies other than this one have been done on stream insects. Because aquatic biota, including bacteria (Frankel et al. 1978) and several species of aquatic vertebrates (Kirschvink 1989) contain magnetite, and some of those species respond to E.L.F. fields in water, it is possible that aquatic insects can detect E.L.F. fields and alter their responses accordingly.

Structural Community Indices: Taxon Diversity (H'), evenness (J') and taxon richness (S) as developed by Shannon and Weiner (see Tramer 1969) have been shown to be useful in the detection of alterations, both natural and anthropogenic, in the community structures. These indices have been central to studies on effects of rock size and microspatial complexity (Hart 1978), p-cresol (Stout and Cooper 1983) and construction of impoundments (Ward and Stanford 1979) on stream dwelling benthic invertebrates. As this is the first study aimed at looking at possible effects of E.L.F. on stream dwelling invertebrates, indices such as these are expected to be useful in the detection of both natural environmental and of E.L.F. operational effects on invertebrates in the Ford River, Michigan.

In general, benthic insect samples include a large number of chironomids (Chironomidae). Our samples can contain up to 3,000 individuals. Because identifications to genus, let alone to species level, are very time consuming for large numbers such as these, efforts at adjusting to possible differences in numbers of taxa among the two experimental (FEX and FEX LINE) and the reference (FCD) sites were made. Structural community indices were computed both with and without chironomids at each of the two sites, and separate analyses were performed on the three data sets to determine whether the unavoidable bias for this taxonomic family unit differentially affected the indices at the three sites.

Functional Community Indices: The most encompassing index, total insect biomass, was used to determine whether there might be dramatic effects, owing to E.L.F. operation, on the production of benthic insects. This index was also segregated into functional units, known as functional feeding groups (See Merritt and Cummins 1984). Mass values for collector-gatherers, filter-feeders, grazers, shredders, and predators, as well as for chironomids as a taxonomic grouping were determined at each site over time with the rationale that E.L.F. may affect some functional feeding groups more than others. If, for example, E.L.F. effects impacted primary producers in the stream, the insect functional feeding group to first respond may be the collector-gatherers and grazers that consume periphyton. In addition, a synthetic index, predator/prey ratio, was generated as a monitoring tool to determine whether the interactive dynamic of potential prey and potential predators in the system were altered before versus after E.L.F. activation.

In addition to the above functional community indices, changes in growth rates or patterns were monitored for six taxa, which are, in the main, collector-gatherers or grazers. If their major source of nutrition were affected by E.L.F. operations, then growth patterns and rates of these consumers of primary production may be altered as well. Efforts were made at selecting species represented by moderate numbers at the three sites to minimize low numbers problems during statistical procedures.

Statistical analyses include power tests, coefficient of variation values, Student-t tests and 2-Way ANOVAS comparing biological parameters over time at the sites. ANCOVAS and within-site multiple regressions were used to relate physical factors that had the highest correlation coefficients with biological parameters (See 1989 Annual Report). ELF cumulative ground field exposure values were also included in the multiple regression tests. An intervention analysis test, the B.A.C.I. (Stewart-Oaten et al. 1986) was used. B.A.C.I. tests use only sample means, so much of the data are lost by this

method. Further, variations around mean values tend to be high in field-derived data as compared with laboratory-derived data. Dr. Abdul El-Shaarawi of the Canadian Center for Inland Waters (with whom ITTRI is consulting) is presently utilizing some of the data in this Element to improve the rigor of the test. Possibly, in the Revised Annual Report, 3.A.C.I. tests, based on residuals from prior statistical tests rather than on sample means, will be completed and compared with the conventional procedure for B.A.C.I. tests.

In this report all statistical tests were performed on seasonal data groupings, so only Two-Way rather than Three-Way ANOVA tests are herein presented. Data are grouped into three seasons: Spring (April, May), Summer (June, July, August), and Autumn-Winter (September through November or December). Data analyses based on seasonal groupings rather than on all months together was a decided improvement (See Three-way versus Two-way ANOVAS in 1990 Annual Report) because coefficient of variation values for most of the biological parameters were lower during the summer stable period as compared with the spring and fall transition periods for the insects in the river. During the spring, both spring run-off, as reflected in high fluctuations in discharge and water temperatures, and changes in taxa and biomass are at their highest. During the fall, alterations in species composition and increases in growth rates of fall-winter growing species affected CV values as well. Our rationale was that the most probable season for the detection of subtle E.L.F. effects may be during the summer "stable" periods.

E.L.F. fields may not operate in biological systems in ways similar to other anthropogenic agents. This may make it difficult to determine proper measures of exposure (e.g., intensity, frequency, electromagnetic excursions during activation and deactivation periods) for relating those exposures to biotic responses (O.T.A. 1989). One may not be able to make simple assumptions regarding dose-response curves. However, as a first approximation, we used cumulative ground field exposure values which are daily ground intensity times duration values summed over the incubation period of the samples. For this report, cumulative exposure values were used as one of three physical independent variables in a series of multiple linear regressions for nine separate biological parameters. Although initial activation occurred in late May of 1986, full power over extended periods began only in the fall of 1989. Our analyses at this time include benthic insect identifications and counts through November of 1990. Before ELF activation data run from the fall of 1983 through the spring of 1986. After ELF activation data run from the summer of 1986 through November of 1990.

Materials and Methods

From November of 1983 through September of 1991, 60 micron Nytex mesh lining half cylinder (18 x 28 x 10 cm) plastic sampler baskets were filled with benthic substrata and buried flush with the stream bottom at FEX and FCD. In June, 1990, a new site downstream from FEX was selected, based on E.L.F. field measurements. The new site, we call FEX.LINE is a definite improvement over the original FEX experimental site with respect to E.L.F. field intensities. However, before impact data sets are not available for this site. Therefore, data from June 1990 through November 1991 for this site will be compared with FEX and FCD (One-Way ANOVA) to determine whether the new experimental site is similar to FEX or FCD before deciding whether this site addition is justified, given the additional work necessary. If the data are statistically similar to those from FEX, we still lack any ability to compare prior with post ELF activation for this new site. Further, if there are significant differences between this site and the FEX site, any possible ELF effects using this new site may be undetectable unless many more than two or three years of accumulated data are available for comparison with FCD.

From May through September each year, seven replicates for each site were collected monthly, with replacement. Each September, sufficient samplers were placed at the sites to allow for late fall, winter, and early spring collections. (After 1986, January through March collections were excluded, owing to past sampling difficulties.) Meier et al. (1979) showed that 30 to 39 days' incubation of samples in substrates in southern Michigan showed the maximum numbers of individuals colonizing substrates. Our colonization studies in 1983 showed that 30 days' incubation was the most parsimonious incubation period (1984 Annual Report).

Samples were processed by placing samplers in separate buckets, washing substrata thoroughly and retaining the suspended animals in a 60 micron mesh soil sieve. Animals were preserved in 80% ethyl alcohol. In the laboratory, insects were picked from detritus and then separated to order level for five of the seven samples. Next, specimens were identified to the lowest taxon possible, and measured to the nearest mm for biomass estimates (after Smock 1980). Numbers of individuals, taxon diversity (H'), richness (S'), evenness (J') and percent numerical dominance for selected species were determined for each sample. Total sample biomass, biomass for functional feeding groups (after Merritt and Cummins 1984), percent biomass for each functional group relative to total biomass, and mean dry mass per individual (MDW/IND) values were computed. Data for this report extend to November, 1990. (Years, ELF cumulative ground field exposure for each sampling period,

stream discharge, chronological time, and physiological time [cumulative degree days] were used as independent variables.) Data came from ambient monitoring of discharge and from maximum-minimum daily water temperatures at each site. Before installation of the automatic ambient monitoring system in April and after the system was dismantled in late October, a chart recorder recorded daily maximum - minimum temperatures at FCD. Before 1988 when chart recorders were not used, estimates of water temperatures based on monthly visits to the sites were made for March and November each year.

MDW/IND values were plotted against chronological time and/or against physiological time. All six species monitored for changes in MDW/IND values have major growth periods during the summer months.

Results and Discussion

Structural Community Indices

Taxon diversity, evenness, richness, number of individuals, and percent dominance of chironomid numbers for each sample were selected. In prior years, 3-Way ANOVA tests were performed on the entire data set to see whether there were year, month, and site differences. Analysis of trends and of coefficient of variation (CV) values for the biological parameters showed that there were clear differences among seasons. Months were coalesced into seasons, based on the trends and CV values. Spring (April, May), Summer (June - August), and Fall (September - November) seasons were therefore analyzed separately. Figures 4.1 through 4.4 show CV values for four of the structural parameters. They illustrate the differences in mean values relative to sample variances from season to season and underscore the rationale for treating seasons separately. Taxon Diversity (H') and evenness (J') values oscillated the most during the spring season. Taxon Richness (S') and numbers of individuals had the lowest values and least oscillations during the summer season. Coefficient of Variation values for H' and J' between the two sites, FEX and FCD, were least similar during the spring transitional period; but richness and numbers of individuals were most similar in that season. These differences in CV values for the structural community parameters are not masked by ANOVA tests or by multiple regression tests because replicates rather than sample means are used. However, B.A.C.I. tests use only sample means, and are affected by high CV values. Thus, 2-Way ANOVA tests with year and site as the main effects, and multiple regression tests relating physical factors with biological factors are presented first. B.A.C.I. test results and a discussion of the test value are presented second.

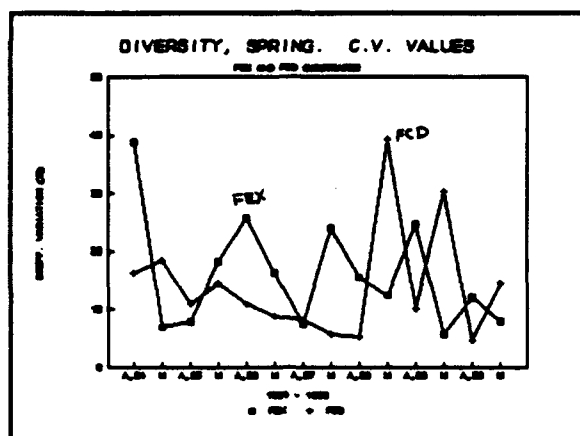


Figure 4.1A. SPRING. April-May

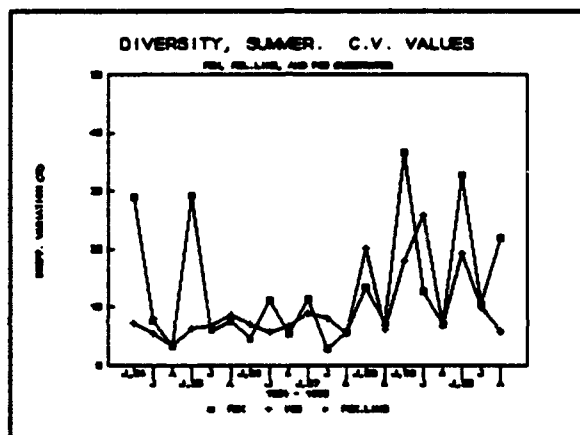


Figure 4.1B. SUMMER. June - Aug.

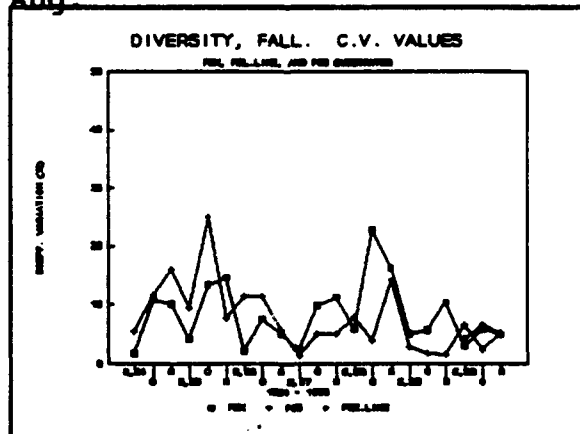


Figure 4.1C. FALL. Sept.-Nov.

Figures 4.1A, 4.1B, 4.1C. Coefficient of Variation values for diversity, without chironomids. FEX (squares), FCD (X's), FEX.LINE (diamonds). 1984-90. A: SPRING, B: SUMMER, C: FALL

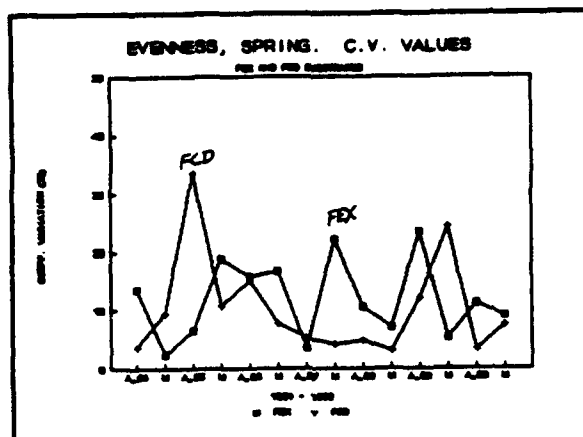


Figure 4.2A. SPRING, April-May

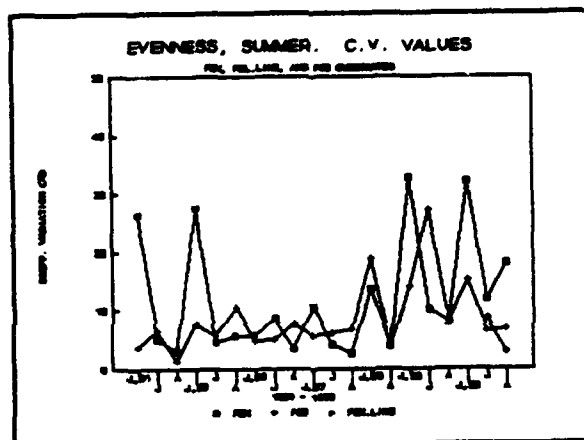


Figure 4.2B. SUMMER, June-Aug.

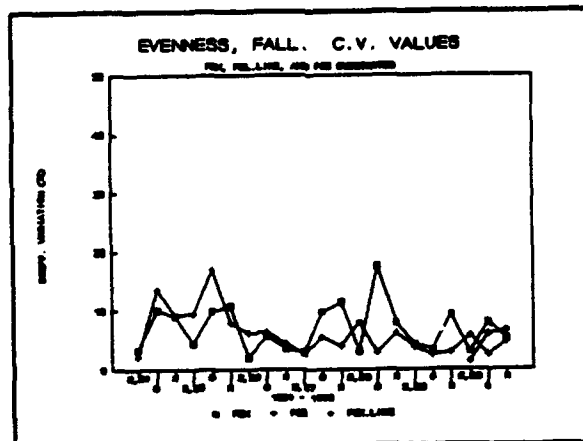


Figure 4.2C. FALL, Sept.-Nov.

Figures 4.2A, 4.2B, 4.2C. Coefficient of Variation values for Evenness, w/o chironomids. FEX (squares), FCD (X's), FEX.LINE (diamonds). 1984-1990. A: SPRING B: SUMMER C: FALL

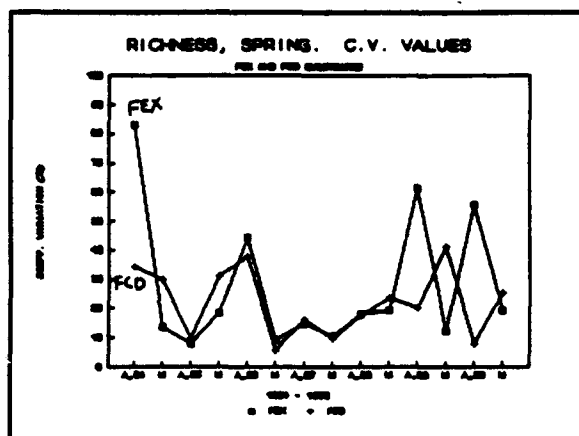


Figure 4.3A. SPRING. April-May

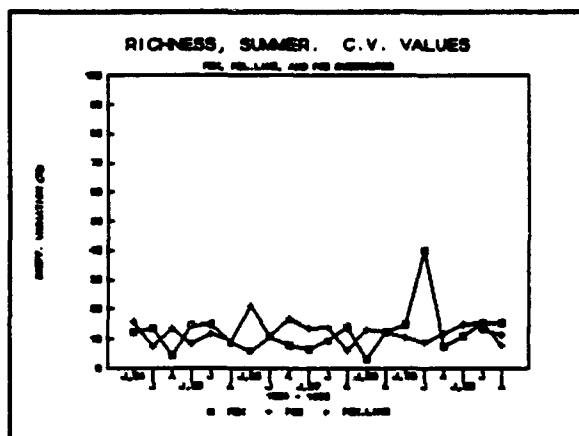


Figure 4.3B. SUMMER. June-Aug.

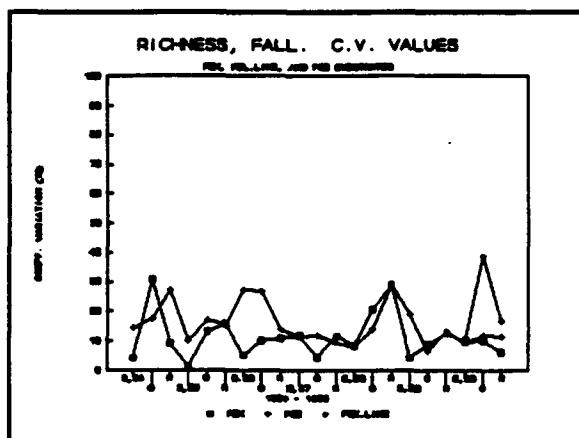


Figure 4.3C. FALL. Sept.-Nov.

Figures 4.3A, 4.3B, 4.3C. Coefficient of Variation values for Richness, w/o chironomids. FEX (squares), FCD (X's), FEX.LINE (diamonds). 1984-1990. A: SPRING B: SUMMER C: FALL

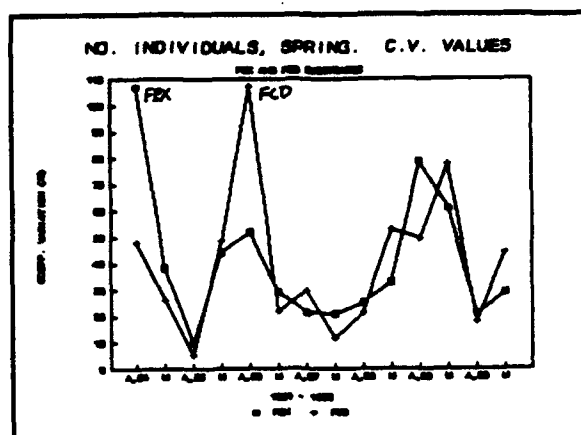


Figure 4.4A. SPRING. April-May

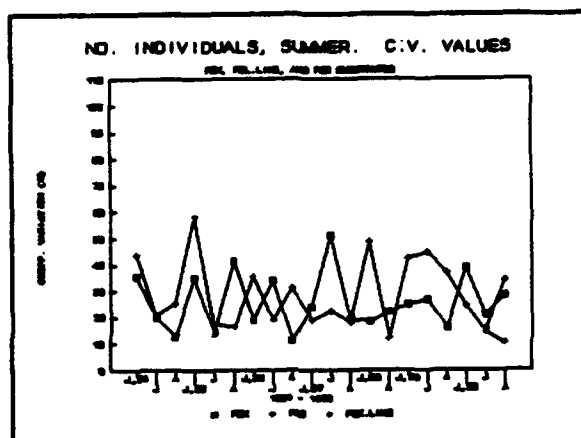


Figure 4.4B. SUMMER June-Aug.

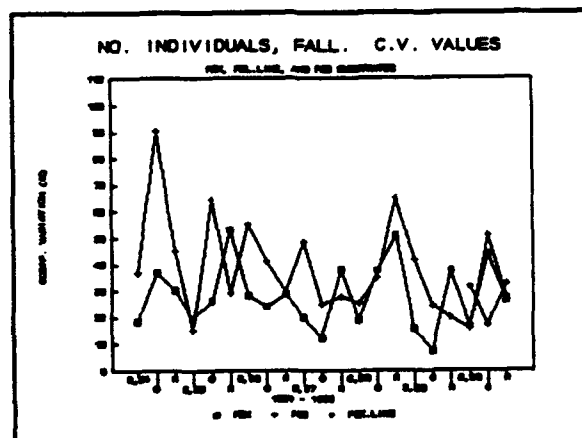


Figure 4.4C. FALL. Sept.-Nov.

Figures 4.4A, 4.4B, 4.4C. Coefficient of Variation values for Numbers of Individuals, w/o chironomids. FEX (squares), FCD (X's), FEX.LINE (diamonds). 1984-1990. A: SPRING B: SUMMER C: FALL

Two-way ANOVA tests were performed, season by season for H', J', S', numbers of individuals, and % chironomid dominance with chironomids as a single taxonomic unit (Table 4.1).

TABLE 4.1
2-Way ANOVA Tests for Seasonal Differences, FEX vs. FCD
Structural Community Parameters, WITH CHIRONOMIDS
F VALUES, LEVELS OF SIGNIFICANCE

Parameter, source	D.F.	Spring	Summer	Fall
DIVERSITY				
Site	1	11.65***	0.07 n.s.	26.35***
Year	6	9.82***	9.06***	9.78***
Site, Year	6	1.41 n.s.	2.02 n.s.	1.78 n.s.
EVENNESS, Arcsin.				
Site	1	9.75***	3.86 n.s.	27.58***
Year	6	8.30***	9.22***	16.17***
Site, Year	6	0.94 n.s.	1.67 n.s.	1.56 n.s.
RICHNESS				
Site	1	6.21**	30.19***	7.91**
Year	6	13.88***	16.57***	15.69***
Site, Year	6	2.02 n.s.	1.66 n.s.	1.58 n.s.
NO. INDIVIDUALS				
Site	1	20.76***	241.53***	7.06**
Year	6	10.54***	15.63***	2.60*
Site, Year	6	2.58*	6.33***	1.19 n.s.
CHIRONOMID DOM.				
Site	1	14.54***	8.91*	44.14***
Year	6	11.31***	2.99**	26.14***
Site, Year	6	5.11***	2.01 n.s.	1.48 n.s.

p < .05 = *; p < .01 = **; p < .001 = ***

ERROR D.F.

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When chironomids, as a single taxonomic unit, were included in the analyses, there were no significant interactions between years and sites for diversity, evenness, and taxon richness during the spring, summer, and fall seasons over the years (Table 4.1). During the summer season there were no site differences for H' and for J' . Taxon richness, numbers of individuals, and numerical dominance of chironomids showed significant year and site differences for each of the three seasons. Chironomids can dominate other taxa in the samples. Figure 4.5 shows that, in general, chironomids dominate the samples more at FCD than at FEX (more points are below the zero difference line). This higher dominance at FCD results in both H' and J' being lower at FCD relative to FEX when chironomids as a single taxonomic unit are included in the Two-Way ANOVA tests seen in Table 4.1.

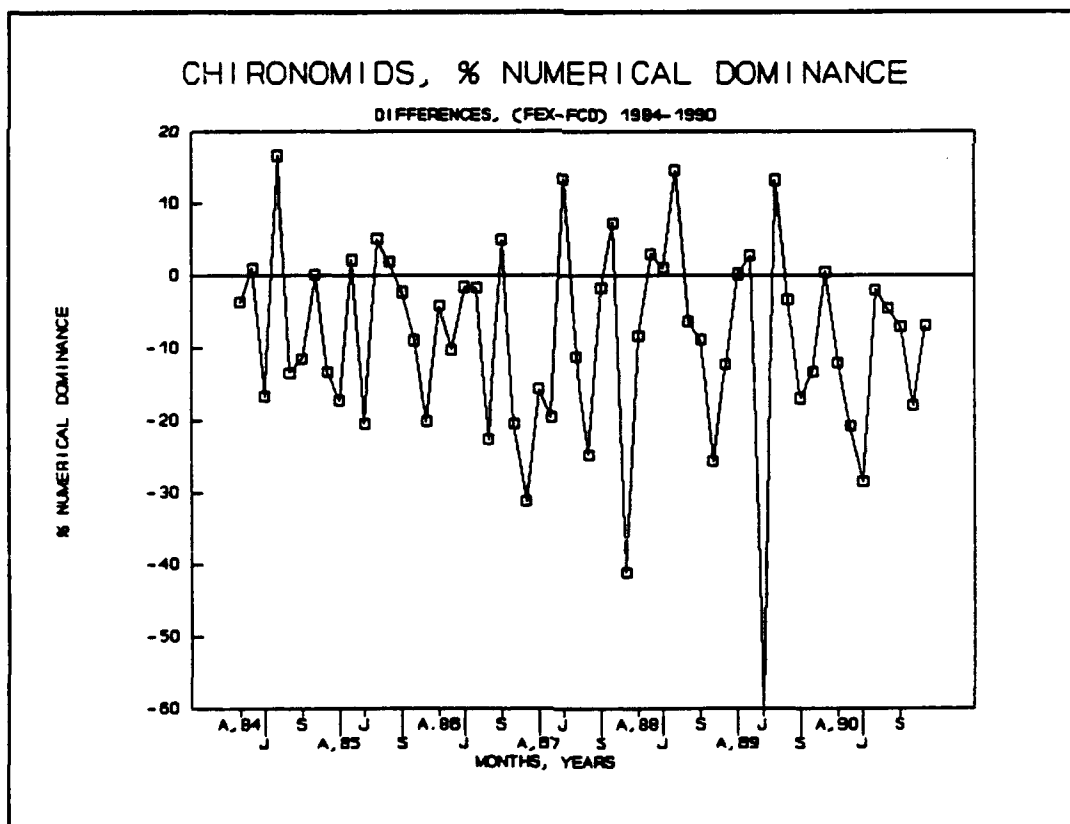


Figure 4.5. Differences in mean numerical dominance of chironomids. FEX - FCD. April, 1984 - November, 1990.

2-Way ANOVAS without chironomids were performed to minimize the bias inherent in having differential numbers of chironomids at the two sites (Table 4.2). Two-Way ANOVA values for H' and J' without chironomids are more reflective of the actual samples, given the limits of our time for identifications. Both summer and fall seasons lacked significant interaction terms for H' and J' when chironomids were excluded from the tests. Significant main effects and interaction terms occurred for numbers of individuals, whether or not chironomids were included in the analysis. Numbers of individuals varied greatly and CV values for them were high over the seasons (Figures 4.4A - 4.4C).

TABLE 4.2
2-Way ANOVA Tests for Seasonal Differences, FEX vs. FCD
Structural Community Parameters, WITHOUT CHIRONOMIDS

F VALUES, LEVEL OF SIGNIFICANCE

Parameter, Source	Degrees of Freedom	Spring	Summer	Fall
DIVERSITY				
Site	1	8.69**	11.87***	2.66 n.s.
Year	6	2.68*	5.15***	9.50***
Site, Year	6	2.43*	1.10 n.s.	1.44 n.s.
EVENNESS, Arcsin.				
Site	1	20.22***	29.01***	17.80***
Year	6	5.03***	2.98**	6.72***
Site, Year	6	4.31***	1.39 n.s.	1.68 n.s.
NO. INDIVIDUALS				
Site	1	28.40***	201.33***	81.93***
Year	6	8.68***	9.15***	8.19***
Site, Year	6	3.61**	4.15***	3.21**

p < .05 = *; p < .01 = **; p < .001 = ***

ERROR D.F.

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Diversity values for any given spring from 1984 through 1990 differed between sites (Figure 4.6A). However, in the summer months, patterns between the two sites were similar, with June of each year showing the lowest values relative to the remaining months of summer (July, August) at the two sites (Figure 4.6B). There were no significant interaction effects in the summer season (Table 4.2). The fall period was similar to the summer in that both sites tracked each other each year (Figure 4.6C). In that season, there were no significant site differences nor significant interaction between years and sites. However, year to year fall fluctuations were significantly different. This was especially apparent in November of 1986 and 1987 when there were no depressions at either site (Figure 4.6C). Late fall and winter months were very mild. Not only did H' remain high, but numbers of individuals remained at high levels as well (Figure 4.9C).

Evenness values showed significant site and year interactions during the spring months (Table 4.2; Figure 4.7A). In 1984 J' was higher at FEX than at FCD in the spring. In 1986 and 1987, both J' and H' were much lower at FEX than at FCD. (Note that in May of 1987, the U.S. Fish and Wildlife Service used a lampricide in the Ford River. I was able to collect samples at FCD before the lampricide reached the site, but was unable to do so for the experimental site.). In 1988 and 1989 the two sites were similar, but in 1990, J' at FEX was lower than at FCD. This resulted in the main factors and the interaction term being significant for that season.

Numbers of taxa (S') were usually higher at FEX than at FCD each year (Figures 4.8A, B, and C). During the summer, stable period, FEX had substantially more taxa, resulting in the differences between sites being significant to a p value $< .001$. Samples from FEX over the years almost always yielded more taxa and individuals. The more heterogeneous substrata at FEX may be the main factor relating to a numerically and taxonomically richer insect fauna.

Figures 4.9A, B, and C show that the peak numbers of individuals (excluding chironomids) were usually higher at FEX than at FCD. In spite of this, there were significant interactions between years and sites in the spring and summer seasons. Numbers of individuals vary greatly among samples. In the June of 1989 when numbers of individuals peaked at FEX they dropped to their lowest levels at FCD (Figure 4.9B), resulting in a highly significant interaction term for that season (Table 4.2). This parameter has the highest coefficient of variation values of all nine biological parameters analyzed for this Element (compare Figures 4.4A - 4.4C with Figures 4.1A through 4.3C).

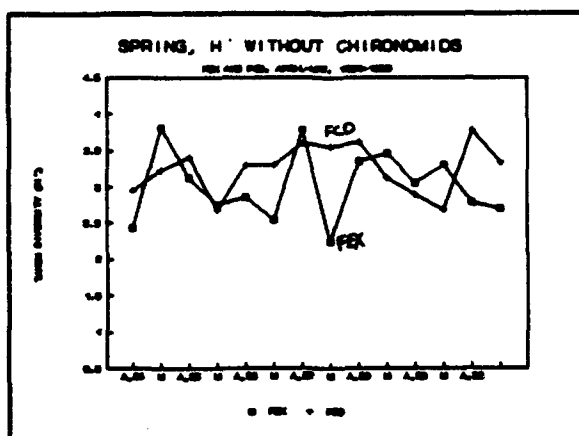


Figure 4.6A. H', SPRING

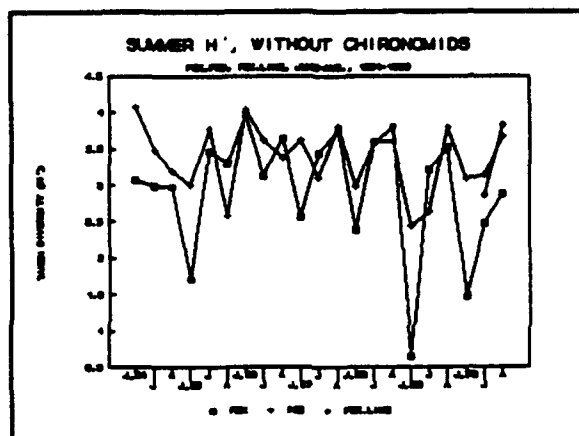


Figure 4.6B. H' SUMMER

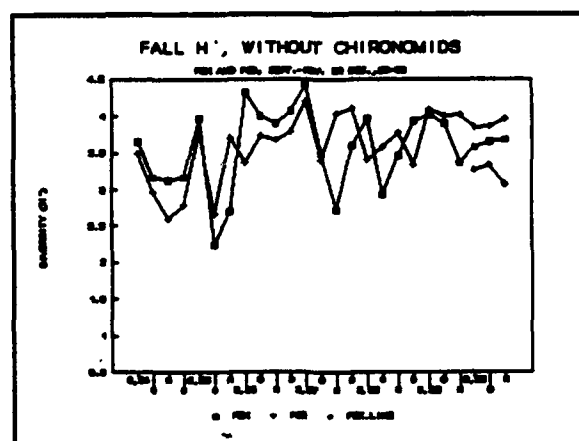


Figure 4.6C. H' FALL

Figures 4.6 A - C: H' without chironomids. 1984 1990. FEX (squares), FCD (X's), FEX.LINE (diamonds). A: SPRING B: SUMMER C: FALL

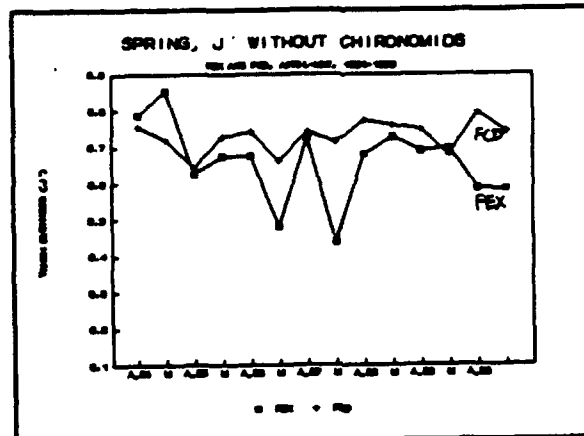


Figure 4.7A. J' SPRING

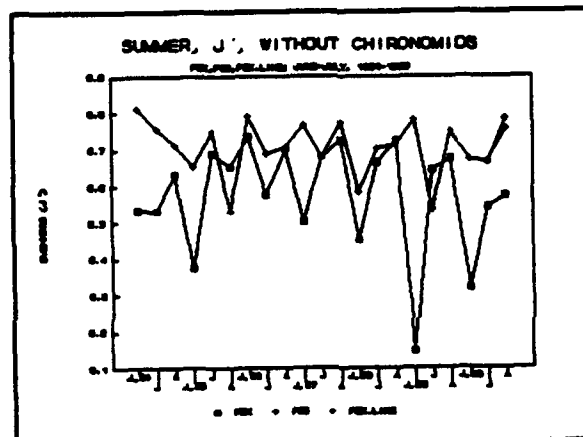


Figure 4.7B. J' SUMMER

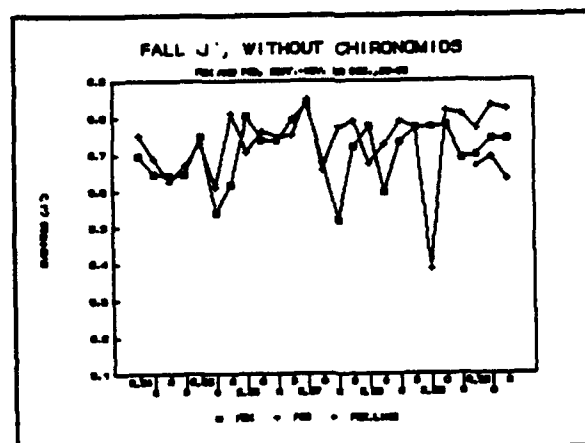


Figure 4.7C. J' FALL

Figures 4.7 A - C. J' without chironomids. 1984 - 1990. FEX (squares), FCD (X's), FEX.LINE (diamonds). A: SPRING B: SUMMER C: FALL

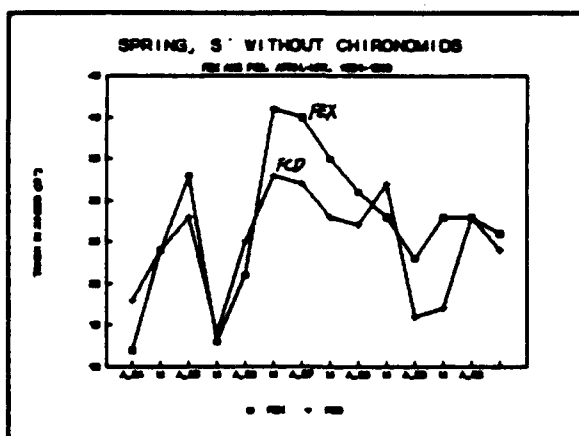


Figure 4.8A. S'. SPRING

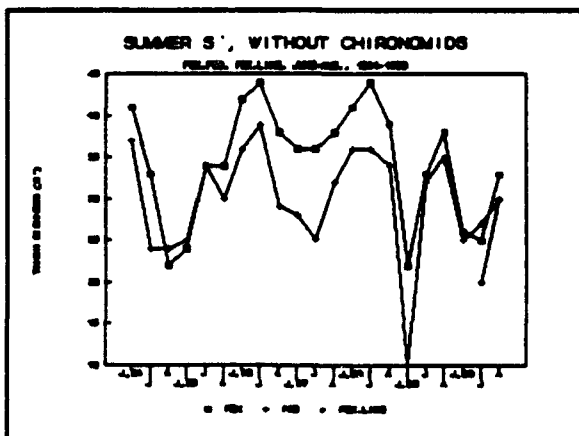


Figure 4.8B. S'. SUMMER

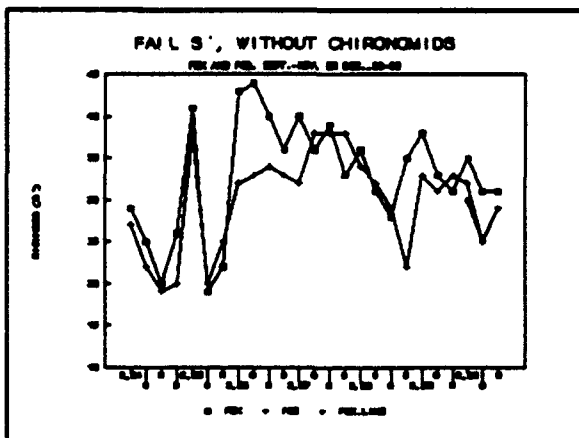


Figure 4.8C. S'. FALL

Figures 4.8A-C. Taxon Richness (S') with chironomids as one taxon, 1984-90.

FEX (squares), FCD (X's), FEX.LINE (diamonds)

A: SPRING B: SUMMER C: FALL

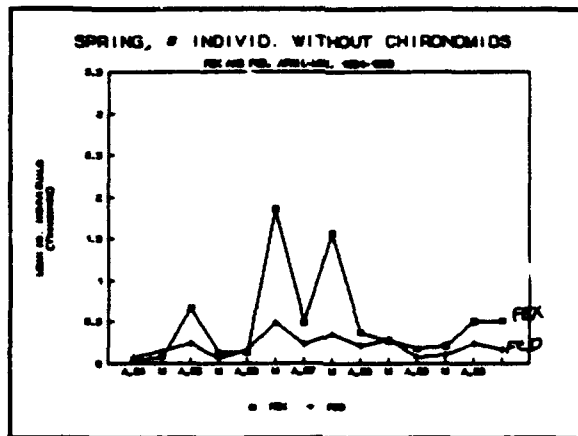


Figure 4.9A. No. Individuals, SPRING

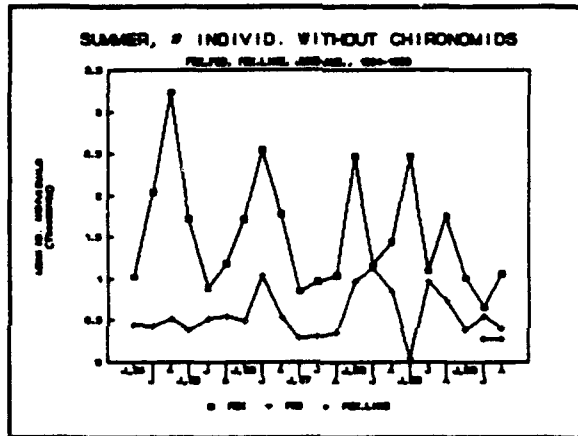


Figure 4.9B No. Individuals, SUMMER

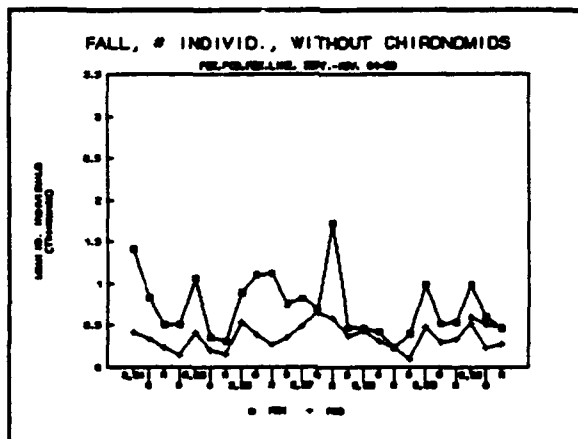


Figure 4.9C. No. Individuals, FALL

Figures 4.9 A - C. Numbers of Individuals, without chironomids. 1984 - 1990.
FEX (squares), FCD (X's), FEX.LINE (diamonds).
A: SPRING B: SUMMER C: FALL

Physical Factors as Related to Structural Community Variables

After ELF activation in 1986, both intensities and durations of ELF fields increased until full power was initiated in the fall of 1989. Although ELF fields may be related to changes in structural community parameters, other physical factors may well be influential in altering those parameters. Discharge and a related physical variable, water temperature, also varied after 1986. In some seasons, namely the spring and fall, discharge and water temperatures differed before versus after ELF activation. These physical variables must be taken into consideration when analyzing whether ELF ground field exposures affected insect structural community parameters.

In order to determine whether discharge, water temperatures, and/or ELF cumulative ground exposure values affected H' , J' , S' , numbers of individuals, or percent chironomid dominance, multiple regression tests were performed for each site, season by season. All physical variables were either averaged (discharge) or accumulated from the beginning to the end of each substrate sampling period. Figures 4.10A, B, and C show the seasonal average discharge values during each month of substrate collection.

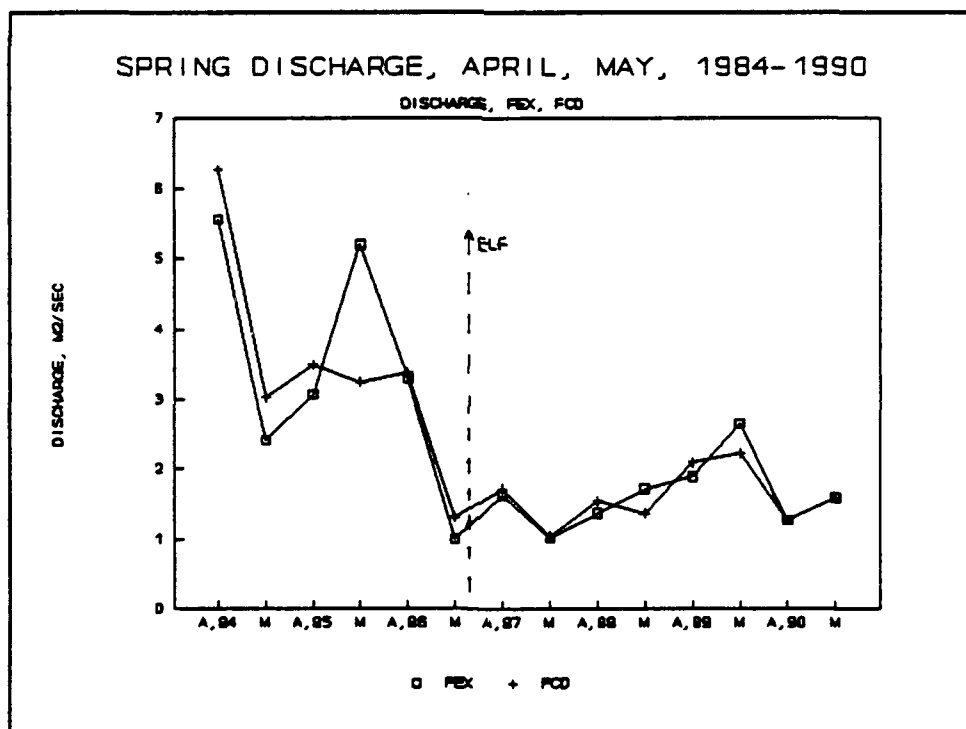


Figure 4.10A. SPRING. Average discharge (m³/sec.) per month at FEX and FCD. 1984 - 1990.

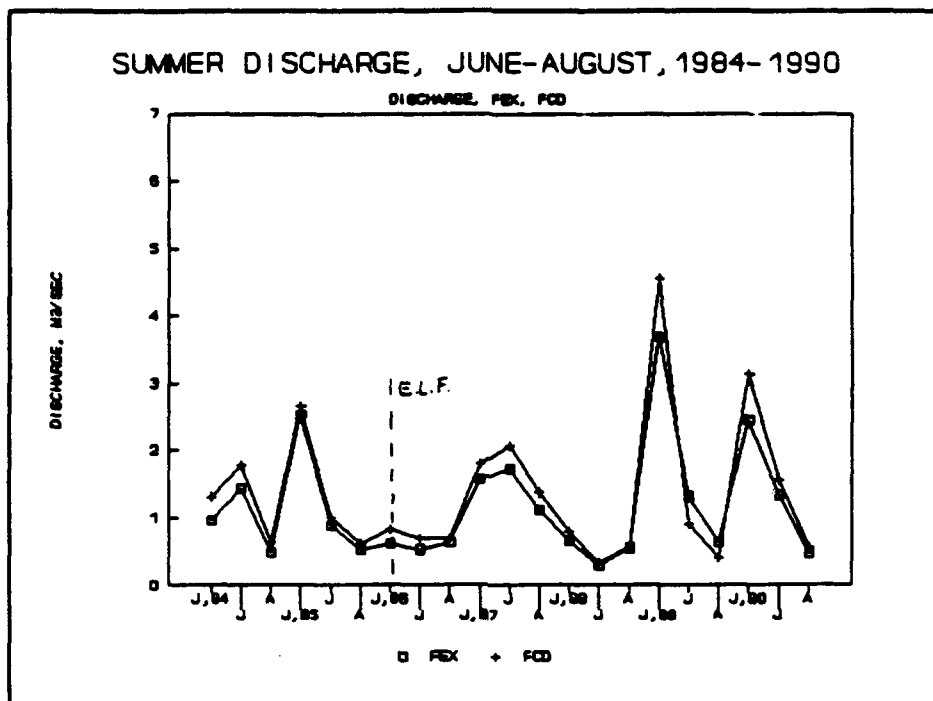


Figure 4.10B SUMMER DISCHARGE

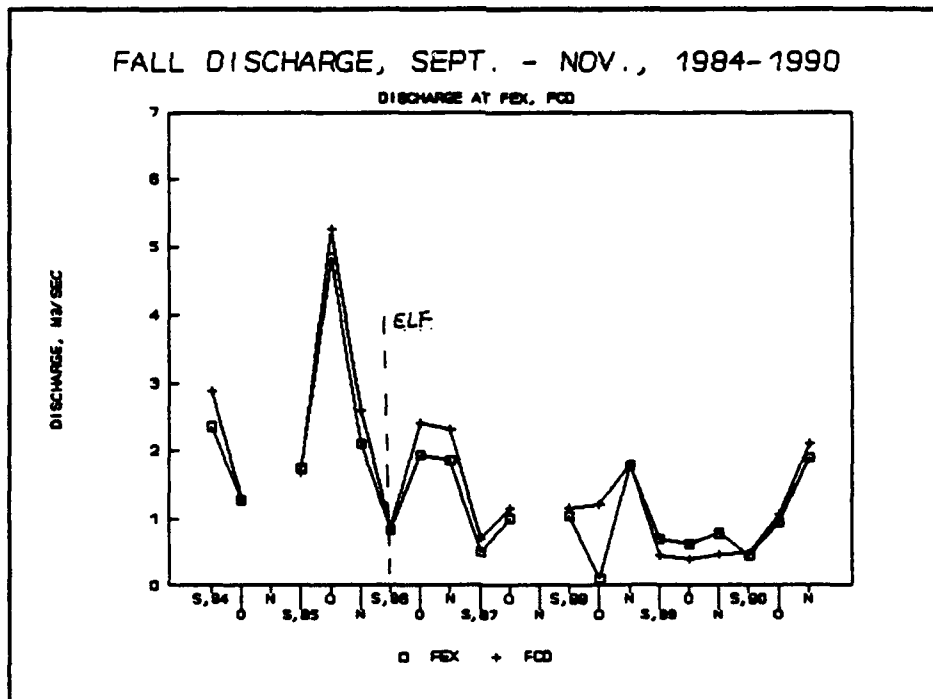


Figure 4.10C. FALL DISCHARGE

Figures 4.10 B,C. SUMMER and FALL average discharge (m³/sec) at FEX and FCD. 1984 - 1990.

Spring discharge values diminished after April of 1986 (Figure 4.10A). They began rising again in 1989 but never approached the values from 1984 through 1986. This pattern could obfuscate any ELF ground field effects because high values prior to ELF activation and then rising (albeit lower) spring discharges after ELF activation could correlate with ELF cumulative exposure values. Summer discharges (Figure 4.10B) are more random through time than are spring discharges and are not expected to be correlated with cumulative ELF exposures. Figure 4.10C shows that discharge values were very high in October, 1985. After September of 1986, discharges were generally lower. In 1990, they rose as compared to 1989 levels. Fall discharge values are not expected to correlate with ELF fields as much as values for the spring months.

Water temperatures at the two sites were used to accumulate degree day values over each year, with the minimum value for accumulation being 2°C. Those cumulative degree day values are presented Figures 4.11A, B, and C, according to season.

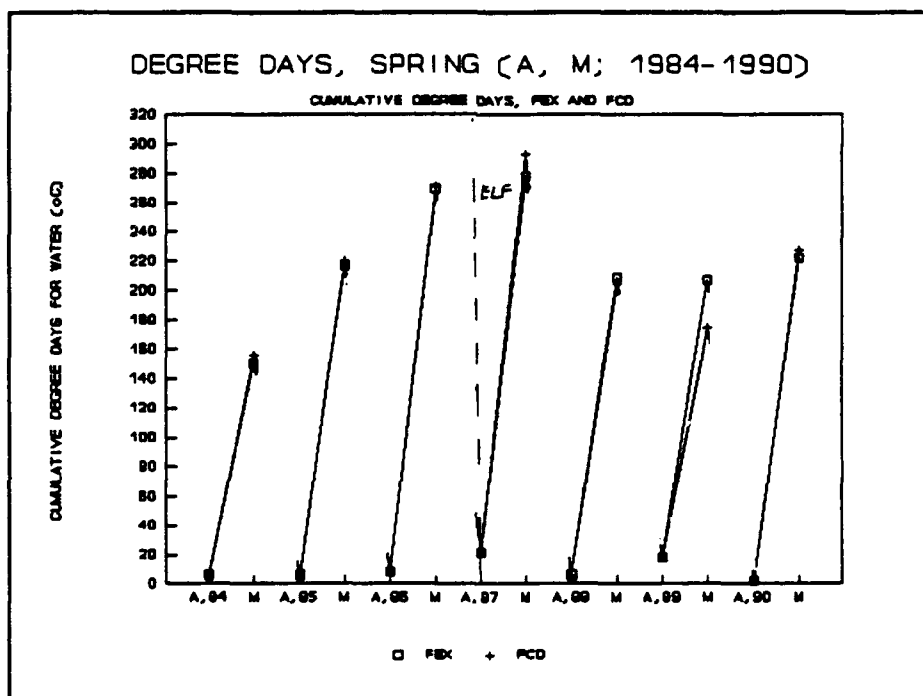


Figure 4.11A. SPRING Cumulative Degree Days

Figure 4.10A. SPRING cumulative degree days (°C) at FEX and FCD, 1984 - 1990. (Note: values between years are connected.)

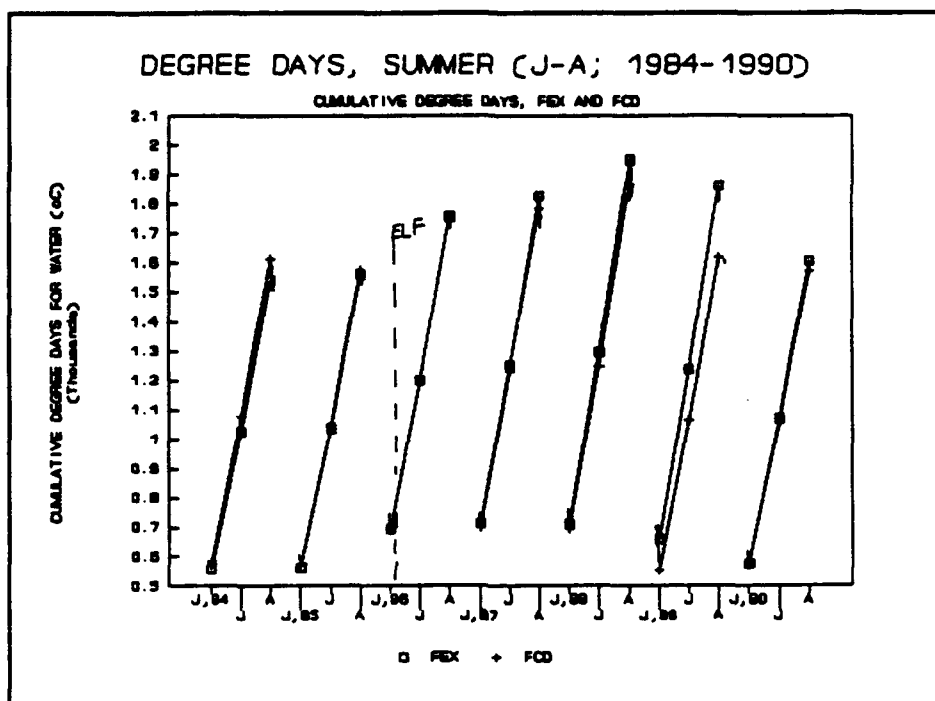


Figure 4.11B. SUMMER

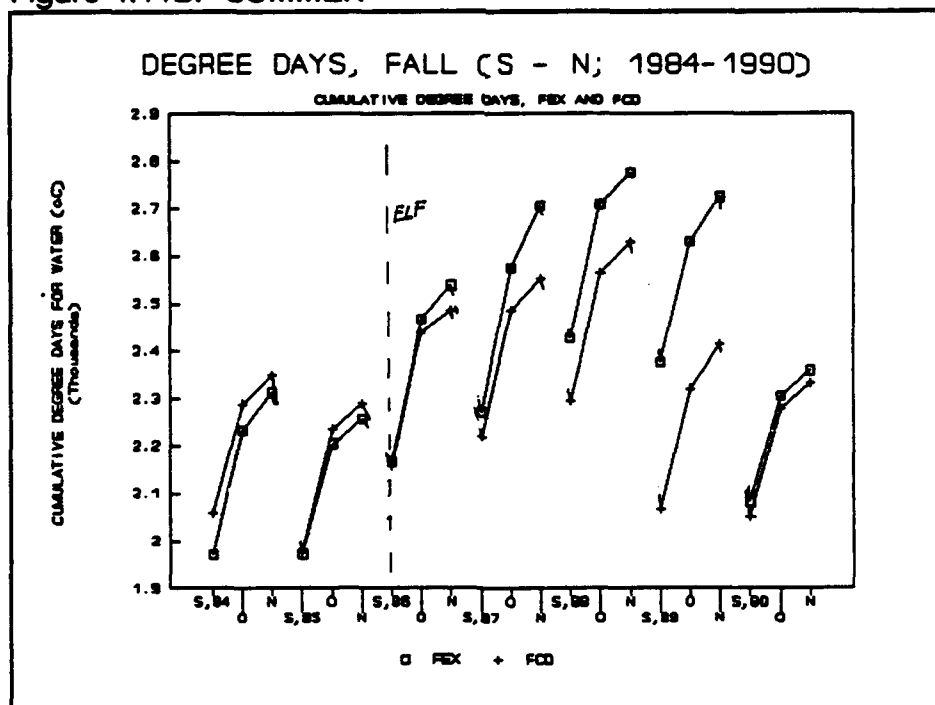


Figure 4.11C. FALL

Figures 4.11 B, C. SUMMER and FALL cumulative degree days (°C) at FEX and FCD. 1984 - 1990. (Note: Values between years are connected.)

Each May, until 1988, cumulative degree days continued to rise. From May 1988 through May 1990 spring water temperatures were similar (Figure 4.11A). In the summertime, the maximum cumulative water temperatures occurred in August of 1988. The last year of our completed data analysis, 1990, was similar to 1985 in terms of cumulative degree days. As full power of ELF fields was operational in 1990 and there was no ELF activation in 1985, one would not expect much in the way of correlations between cumulative degrees and ELF cumulative exposure during the summer season over all years. The fall season generally increased in cumulative degree days over the years until September of 1989, the time when ELF was fully operational. However, the period from the fall of 1986 through the fall of 1990 shows an increase and then a decrease in cumulative degree days. As ELF activity was increased in duration and intensity over that period, one would expect a minimum relationship between cumulative degrees and ELF cumulated exposure after ELF activation.

Cumulative ELF ground field exposure to the insects were determined by taking the date the samplers were put in the stream (Day 0) and then summing the daily exposure values until the samplers were retrieved. The time span was 28 to 30 days for May through October each year. April samples would have been in samplers at the sites from mid-September of the previous year. Figure 4.12 presents the data in arithmetic form, and Figure 4.13 presents the data as a semi-log plot.

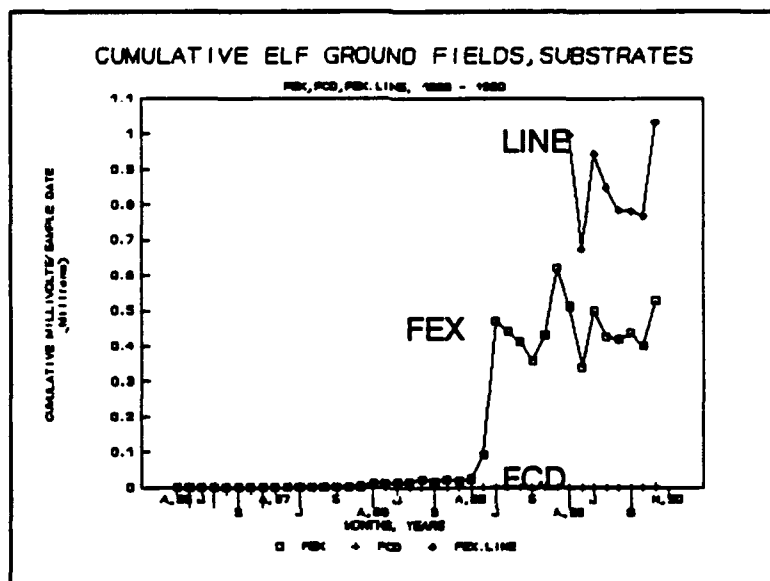


Figure 4.12. Cumulative ELF groundfield exposure at FEX (squares), FEX.LINE (diamonds), and FCD(pluses). April 1986 - November 1990. Arithmetic Plot.

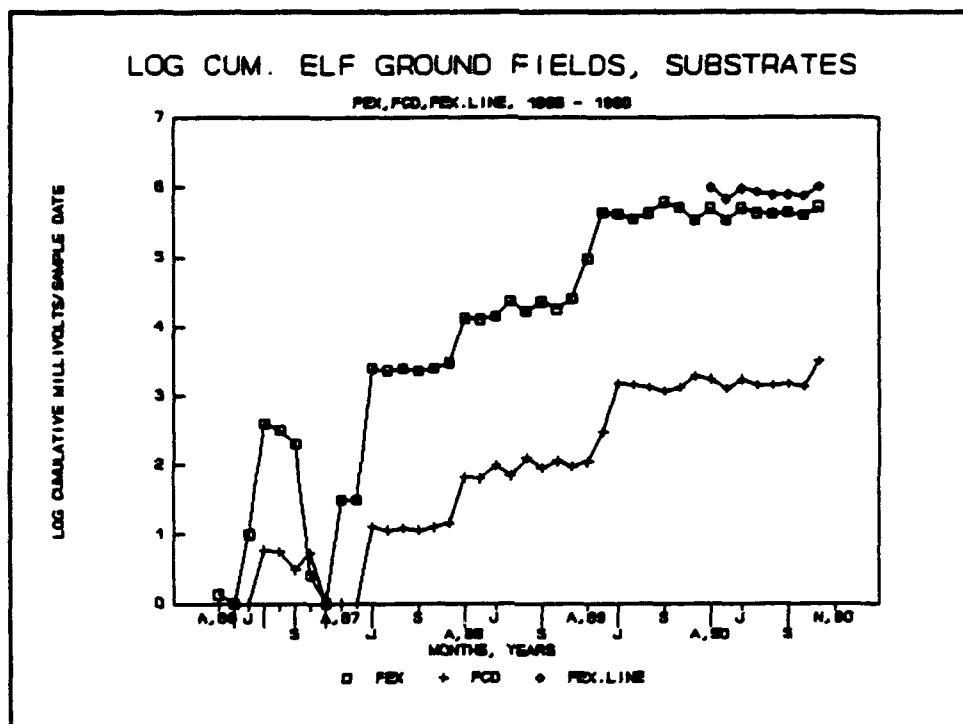


Figure 4.13. Log cumulative ELF ground field exposure, 1986-1990. FEX: squares, FEX.LINE: diamonds, FCD: X's.

Multiple regressions were performed, using years, ELF ground field cumulative exposure, discharge, and cumulative degree days (Table 4.3). The data were grouped season by season and regressions were run on all five structural community parameters for each site separately to see which of the independent physical variables accounted for most of the variation in the biological parameters. If R^2 values were above 0.50 and ELF exposure affected the parameters, one would expect F values at FEX to be high relative to the other independent parameters and low at FCD relative to the other independent parameters.

Diversity, evenness, and numbers of individuals did not include chironomids as a taxonomic unit. Taxon richness values only counted chironomids as one taxon. Percent numerical dominance by chironomids was the ratio between numbers of chironomids to total numbers of individuals. Evenness values were transformed, arc sine of square root of Y, and percent data were transformed (arc sine of square root of Y/100).

Spring: Discharge accounted for much of the variation in the biological variables when the R^2 was above 0.50; namely, numbers of individuals, and

percent numerical dominance by chironomids at FEX and at FCD. F values for numbers of individuals were highest for discharge at each of the sites. ELF exposure F values were high for chironomid dominance at both sites, rather than only at the experimental site. The next largest F values at the sites were for discharge. It appears that because the independent parameter, year, had relative high F values as well, it may be that systematic yearly differences since ELF activation may be more important; e.g., discharge. In the spring months, numerical dominance of chironomids after ELF activation showed a pattern: There was an increasing chironomid dominance from 1987 to 1989 and then a steep decrease at FEX from May of 1989 through May of 1990 (Figure 4.14A). Because chironomid dominance increased over the years after ELF activation, it is expected that years, ELF, and discharge (Figure 4.10A) would be related to one another. They were, both at FEX and at FCD, the reference site.

TABLE 4.3
Multiple Linear Regressions for Biotic Parameters versus
E.L.F. Cumulative Exposure, Discharge, Cumulative Degree Days
Spring (1987-90)

SPRING

Dependent Variables, R² and F Values

<i>Independent Variables</i>	<i>H'</i>	<i>J'</i>	<i>S'</i>	<i># Individ.</i>	<i>Chiro. Dom.%</i>
FEX					
R²	.332	.461	.362	.566	.558
Years	8.836	11.000	0.937	5.248	6.354
ELF	9.307	13.225	0.006	12.840	15.163
Discharge	2.839	15.890	14.671	15.114	13.630
Cum.D.Days	8.755	8.208	0.183	6.669	1.534
FCD					
R²	.267	.132	.424	.571	.646
Years	2.271	0.078	3.469	6.698	48.016
ELF	0.996	0.266	0.569	1.650	32.479
Discharge	8.333	0.006	20.570	35.919	26.316
Cum.D.Days	6.844	5.084	0.475	2.479	1.878

BOLDFACE: WHEN R² > .50

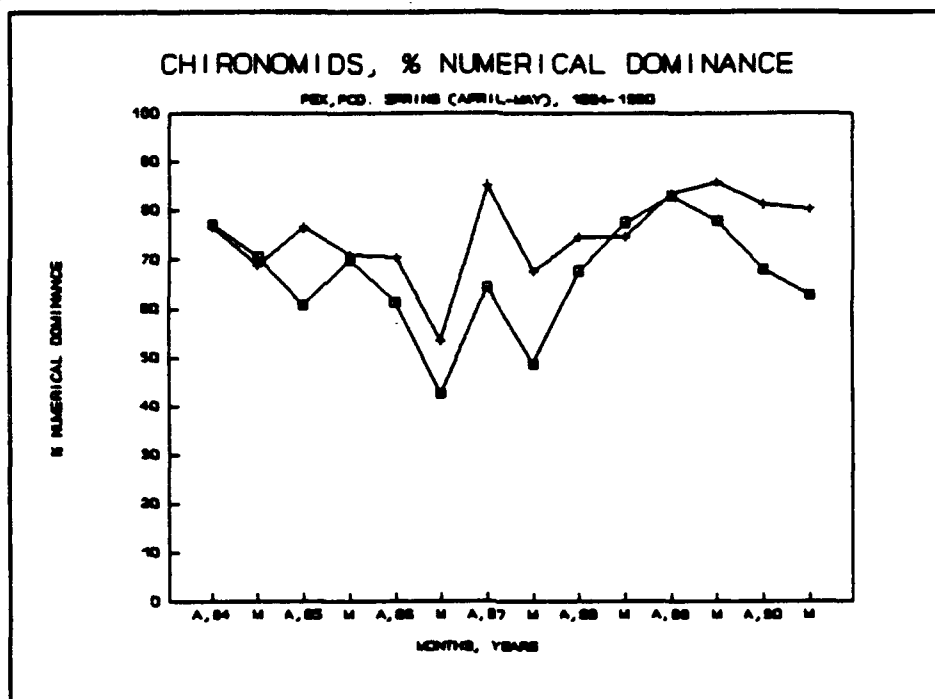


Figure 4.14A. Chironomid numerical dominance at FEX (squares) and FCD (pluses), 1984-1990. SPRING (April, May).

Summer: Coefficient of Multiple Determination values were above 0.50 for four of the five biotic parameters at FEX and for three of the five biotic parameters at FCD (Table 4.4). At FEX, there were high F values for discharge and/or cumulative degree days versus H', J', S', and Chironomid Dominance. At FEX, there were high F values for discharge and/or cumulative degree days versus H', J', and S'. ELF fields were also high for H, J', and chironomid dominance. Most important was the fact the F values for ELF fields were similarly high at FEX, the experimental site and at FCD, the reference site. ELF field exposure increased as years increased. Note that the independent variable, years, also has relatively high F values. Other independent variables are related to years. Because FEX and FCD show high F values for ELF exposure and years, the other independent factors appear to be more related to the dependent variables than ELF exposure. Discharge, after June of 1986 varied over the years, with peak discharges occurring in June of 1989 and June of 1990 (Figure 4.10B). H', J', and S', as well as chironomid dominance dropped dramatically for months with high discharge. Cumulative degree days increased until August of 1988 and then descended again until 1990.

TABLE 4.4
Multiple Linear Regressions for Biotic Parameters versus
E.L.F. Cumulative Exposure, Discharge, Cumulative Degree Days
Summer, 1986 - 1990

SUMMER

Dependent Variables, R² and F Values

<i>Independent Variables</i>	<i>H'</i>	<i>J'</i>	<i>S'</i>	<i># Individ.</i>	<i>Chiro. Dom. %</i>
FEX					
R²	.804	.778	.732	.388	.509
Years	2.862	6.510	18.866	30.373	10.630
ELF	8.929	11.712	6.718	19.198	7.396
Discharge	16.621	11.433	69.348	5.314	20.404
Cum.D.Days	42.502	47.213	5.652	21.703	0.779
FCD					
R²	.642	.538	.751	.406	.182
Years	12.431	7.703	0.305	12.704	4.294
ELF	17.163	11.385	0.119	15.810	4.059
Discharge	0.005	22.225	47.655	36.955	12.424
Cum.D.Days	10.466	15.449	1.906	7.443	4.018

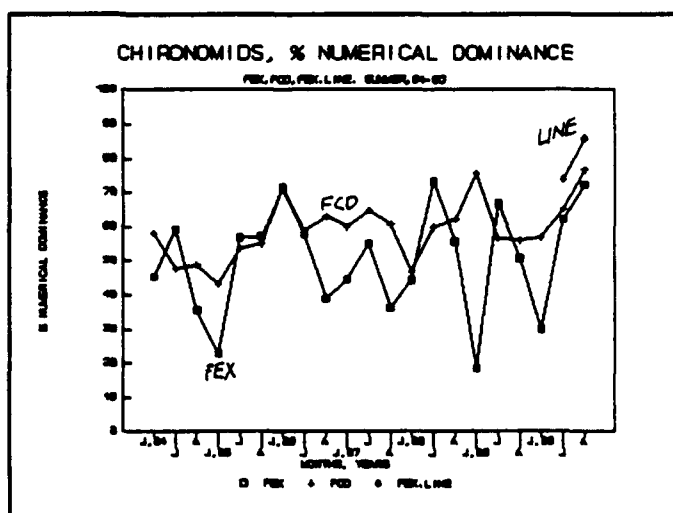


Figure 4.14B. Chironomid numerical dominance at FEX (squares), FCD(X's), FEX.LINE (diamonds) 1984-90. SUMMER (June - August).

Fall: After ELF activation, most coefficient of multiple determination values were above 0.50 at FEX and none were above 0.50 at FCD (Table 4.5). The highest F values were for cumulative degree days at FEX. From the fall of 1986 through the fall of 1989 cumulative degree days increased (Figure 4.11C). Only in 1990 did cumulative degree days drop to the pre-ELF activation levels. Discharge accounted for little of the variance in the biotic parameters, which contrasts with the spring season where discharge accounted for much of the variance. In summary, after ELF activation, biotic parameters in the spring were more related to discharge; in the summer they were related to discharge and/or cumulative degree days, and in the fall they were more related to cumulative degree days. The most harsh non-anthropogenic factor to rheophilic aquatic insect communities is often flooding. When flooding is minimal, changes in water temperatures are effective cues to changes in the insect communities. If flooding occurs during the summer or the fall, one can expect to see biotic responses, which were seen in June of 1989 and 1990.

TABLE 4.5
Multiple Linear Regressions for Biotic Parameters versus
E.L.F. Cumulative Exposure, Discharge, Cumulative Degree Days
Fall, 1986 - 1990

<u>FALL</u>					
<i>Dependent Variables, R² and F Values</i>					
<i>Independent Variables</i>	<i>H'</i>	<i>J'</i>	<i>S'</i>	<i># Individ.</i>	<i>Chiro. Dom. %</i>
<i>FEX</i>					
<i>R²</i>	.619	.456	.754	.708	.677
<i>Years</i>	6.800	3.089	13.889	0.497	1.040
<i>ELF</i>	0.699	0.667	0.421	2.706	3.379
<i>Discharge</i>	0.402	0.079	1.648	0.348	0.304
<i>Cum.D.Days</i>	22.074	10.405	33.412	28.439	2.123
<i>FCD</i>					
<i>R²</i>	.102	.193	.053	.250	.426
<i>Years</i>	0.450	0.386	0.537	1.012	4.489
<i>ELF</i>	0.984	2.082	0.079	3.407	13.133
<i>Discharge</i>	0.010	0.463	0.307	7.316	20.242
<i>Cum.D.Days</i>	1.712	1.585	0.000	1.154	0.960

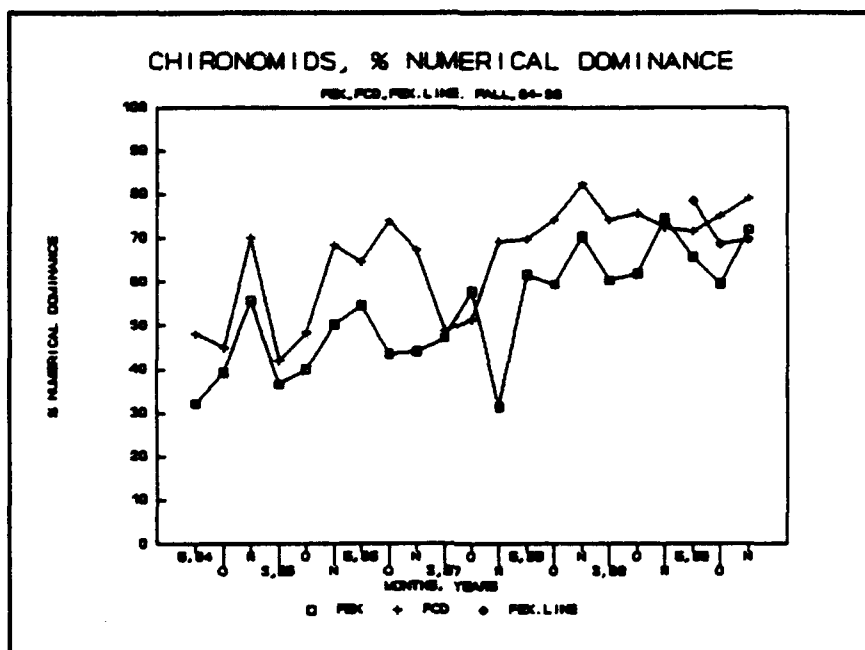


Figure 4.14C. Chironomid numerical dominance at FEX (squares), FCD (X's), and FEX.LINE (diamonds). 1984-1990. FALL (September - November).

The multiple regression analyses included data after ELF activation, and the two sites were treated separately for analysis. Physical factors other than ELF cumulative exposure were often found to be related to the biotic parameters. One type of intervention analysis, the B.A.C.I. method, was used to see whether there were systematic differences before versus after ELF activation. In this analysis, data from 1984 through 1990 are used, and comparisons between the two sites are made. One major drawback of the B.A.C.I. method, however, is that only sample means are used. When variance is high, as is often the case for field-derived data, the B.A.C.I. does not take into account those variances. The B.A.C.I. procedure certainly avoids the problem of pseudoreplication (see Hurlbert, 1984), but the costs of that gain are the losses in incorporation of variation among samples. Resolutions to this dilemma may appear in the next Annual Report, with the help of Dr. Abdul Shaarowi, a biostatistician helping ITTRI in their review of the Reports.

B.A.C.I. tests were performed on the seasonal datasets where chironomids were excluded, so that the effect of identifying chironomids only to family level would not seriously impact H' and J' indices. The primary value in using B.A.C.I. tests is that one can detect a before versus after effect on a large data set. One restriction of the B.A.C.I. method is that one uses only sample

means rather than all the sample values. In order to run the tests, the data set prior to impact (in our case, the years 1984, 1985, and the spring of 1986) must pass the test of additivity, and therefore, not show significance in a linear regression analysis. With the small numbers of values, there is always a chance that the data will not "pass the regression" test. This happened once for diversity, evenness, percent numerical dominance for chironomids, and twice for numbers of individuals.

Table 4.6 presents results of B.A.C.I. tests for structural community parameters on a season by season basis. In the tests, where t-tests were possible, there were significant differences only for J' in the summer season. Thus, for the 10 tests that passed the test for additivity, only one showed a significant before versus after effect.

TABLE 4.6
Results of B.A.C.I. Comparisons for Structural
Community Parameters; Spring, Summer, Fall

Spring BEFORE: 1984-1986, AFTER: 1987-1990
Summer BEFORE: 1984-1985, AFTER: 1986-1990
Fall BEFORE: 1983-1985, AFTER: 1986-1990

Index, Comparison	Trans- form Type	Tukey's Test for Additivity		t-test, Signif.	
		df.	F-value, sig.	df.	T-value sig.
DIVERSITY					
Spring	NO	4	51.57**		n.a.
Summer	NO	4	3.64	19	-0.913
Fall	NO	7	0.30	25	0.44
EVENNESS					
Spring	Arcsin	4	21.06**		n.a.
Summer	Arcsin	4	4.63	19	14.051***
Fall	Arcsin	7	0.76	25	0.765
RICHNESS					
Spring	NO	4	7.63	12	-0.257
Summer	NO	4	6.54	19	-1.291
Fall	NO	7	1.72	25	-1.832

Table 4.6, continued

Index, Comparison	Trans- form Type	Tukey's Test for Additivity		t-test, Signif.	
		df.	F-value, sig.	df.	T-value sig.

NO. INDIVIDUALS					
Spring	log(X+1)	4	5.71	12	-1.128
Summer	log(X+1)	4	135.43***		n.a.
Fall	log(X+1)	7	21.17***		n.a.
CHIRONOMID DOMINANCE					
Spring	NO	4	-7.70	12	0.147
Summer	NO	4	4.60	19	0.433
Fall	Arcsin	7	68.70***		n.a.
* = <.05, ** = <.01, *** = <.001 n.a. = not appropriate					

* = <.05, ** = <.01, *** = <.001 n.a. = not appropriate

Evenness values at FEX oscillated greatly, as compared with values at FCD (Figure 4.2B). In June of 1989 and 1990 (after ELF activation), there were strong floods and the resultant samples from FEX contained few individuals and taxa; J' was even lower than H' in those months. It is possible that these two events contributed greatly to B.A.C.I. significant difference for evenness. Therefore, an ANCOVA using discharge as the independent variable, was run for J' for the summer (Table 4.7).

TABLE 4.7
ANCOVA for Mean Discharge (m³/sec) and J'
1984-1990

Season, Source	d.f.	SS	MS	F, sign.
SUMMER, J'				
Difference among adjusted means				
Adj. Means	1	2.0734	2.0734	32.48***
Error	207	13.2173	.0638	
Diff. between slopes				
Slopes	1	4.8360	4.8360	118.86***
Sum group dev.	116	8.3813	.0407	

Common slope: -.19005; * = $p < .05$, ** = $p < .01$, *** = $p < .001$

Table 4.7 shows that both the means and the slopes for J' versus discharge differed between the two sites. The slope for J' at FEX vs. discharge was -.322; whereas, the slope for J' at FCD vs. discharge was .010. It appears probable that discharge impacted J' more at FEX than any ELF exposure.

Functional Community Indices

Total Insect Mass and Functional Feeding Group Mass:

For this year's Annual Report, two additional biotic parameters were added for analysis; namely, chironomid mass dominance and collector-gatherer mass dominance. Chironomids, even though on an individual basis are small, their high numbers in samples accounts for a large portion of the total biomass. Many of the species of insects we follow for changes in mean dry weight per individual over time are collector-gatherers, and that functional feeding group is expected to respond to any losses in periphyton that might be caused by ELF exposure.

Coefficient of variation (CV) values for the overall functional community index, total insect mass, were lower and fluctuated less during the summer season than during the spring or fall season (Figures 4.15A, B, C).

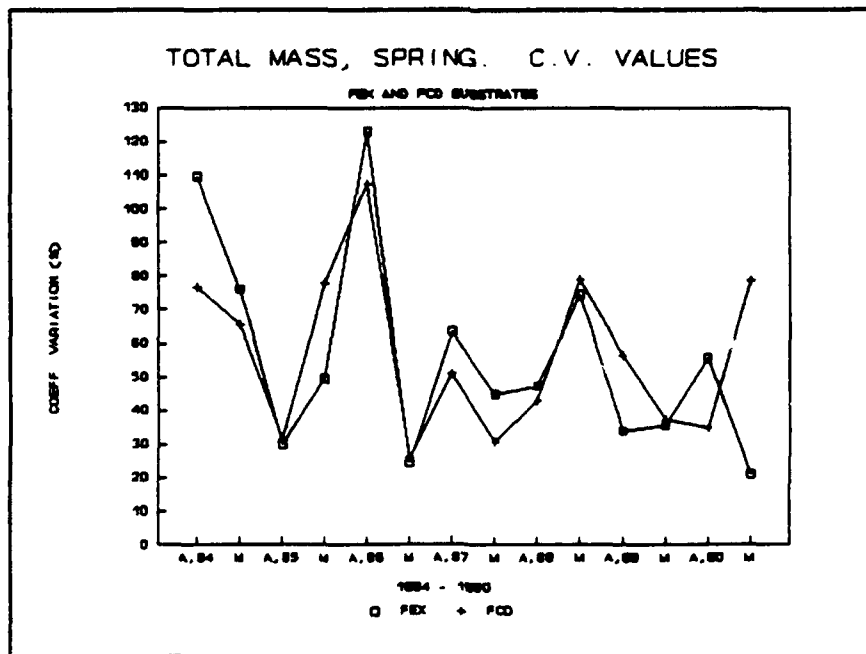


Figure 4.15A. Total Insect Mass C.V., SPRING.

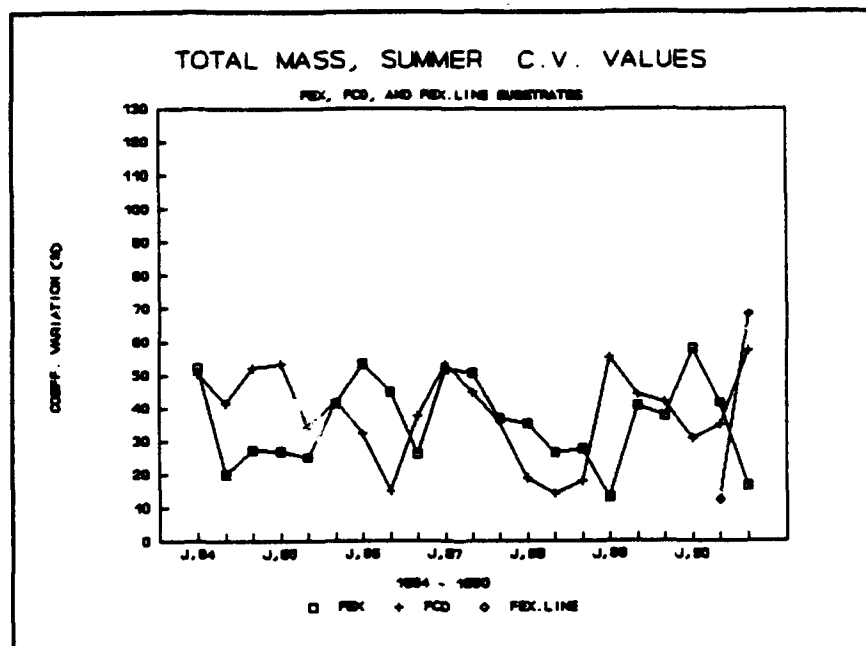


Figure 4.15B. Total Insect Mass C.V., SUMMER

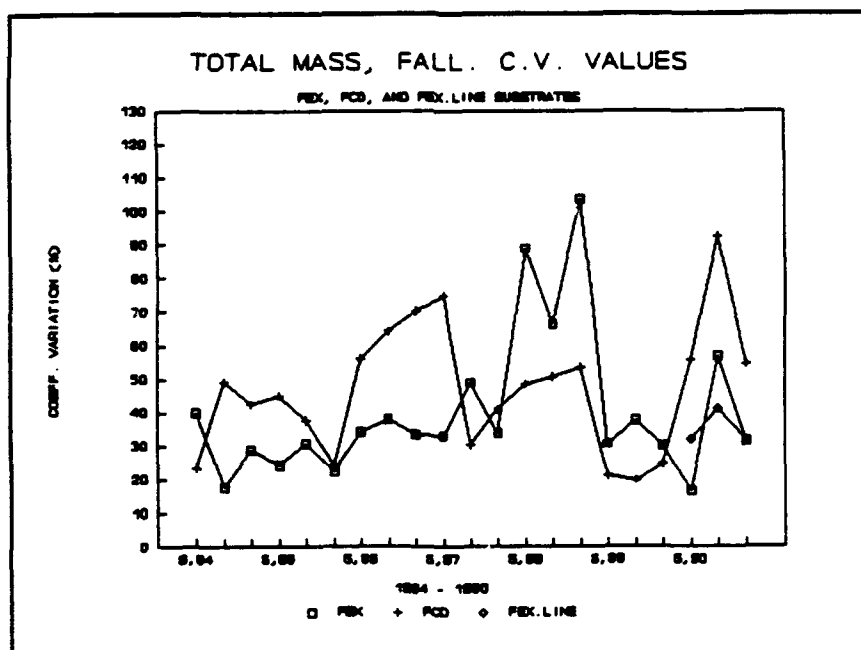


Figure 4.15C. Total Insect Mass C.V., FALL

Figures 4.15B, 4.15C. Coefficient of Variation values for total insect mass, with chironomids. FEX (squares), FCD (X's), FEX.LINE (diamonds). 1984 - 1990.
B: SUMMER C: FALL

The spring period showed the highest CV values (Figure 4.15A). They are related to the high spring discharge values (Figure 4.10A), especially in April of 1984 and May of 1985.

Figure 4.16, a plot of the mean difference between FEX and FCD for total insect mass, shows that peak differences between the two sites occurred at least once a year, even though the amplitude and duration of the differences varied. The peak differences also usually occurred during the summer months. The majority of the points occur above the zero line and indicate that total insect mass is often higher at FEX than at FCD. The only times that insect masses were much greater at FCD than at FEX was in July of 1985, July of 1988 and July of 1990. The higher biomass at FCD was primarily attributable to a predator (Figure 4.17A), *Ophiogomphus colubrinus*, a dragonfly for which we studied movement patterns for the past several years. During the mild fall and winters of 1986 - 1987, the difference between FEX and FCD remained high. Collector-gatherers (Figure 4.18A) and collector-filterers (Figure 4.19A) comprised the bulk of the higher biomass at FEX during those mild periods.

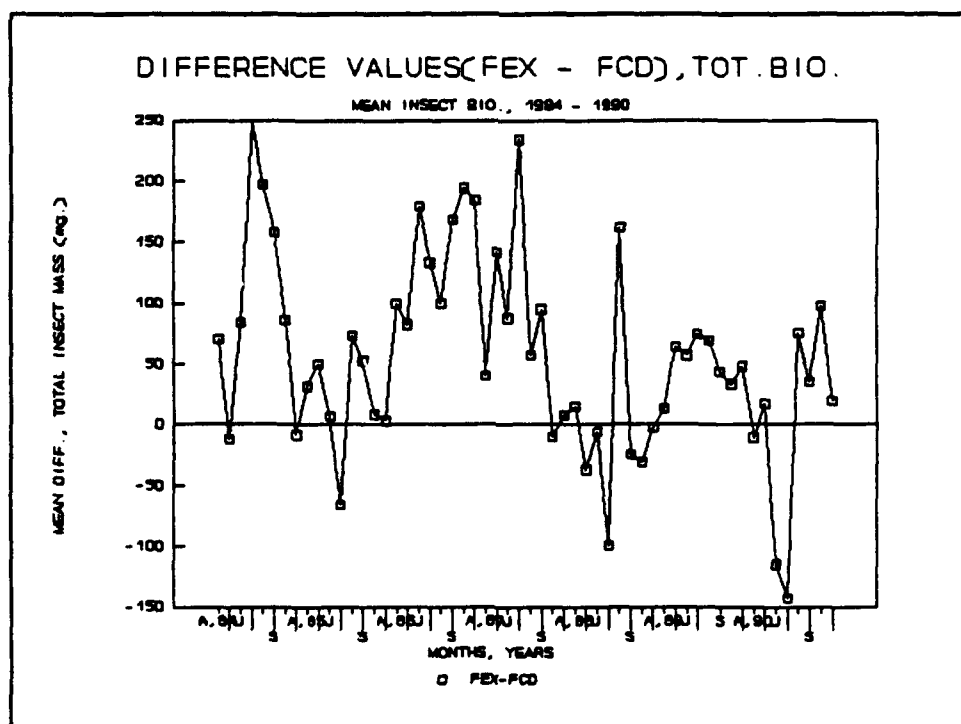


Figure 4.16. Differences between mean total insect mass (mg.) at FEX versus FCD. April through November each year. 1984 - 1990.

The following four pairs of graphs present mean differences between sites for four functional feeding groups (Figures 4.17 - 4.20) in two ways. The first graph of each pair shows mean difference values; the second plot takes the difference of the percent of total mass for the particular functional feeding group between the two sites; e.g., predator mass/total mass X 100 at FEX minus predator mass/total mass X 100 at FCD.

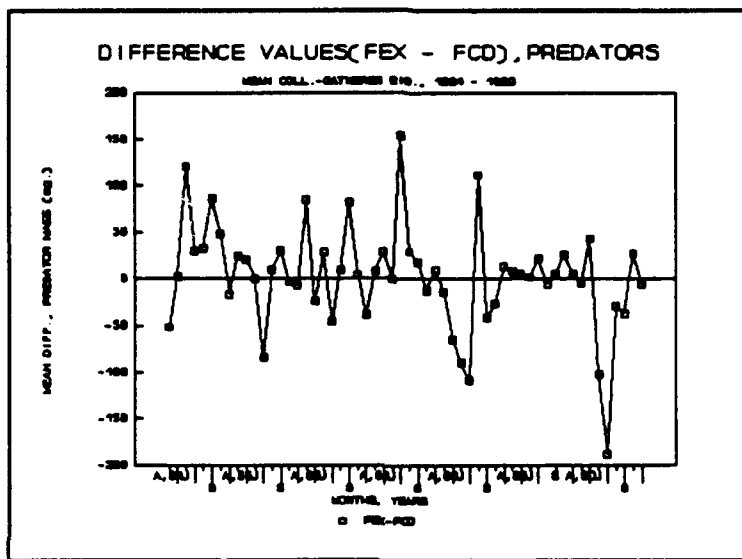


Figure 4.17A. Differences between mean predator mass (mg.). FEX minus FCD. April through November, 1984-90.

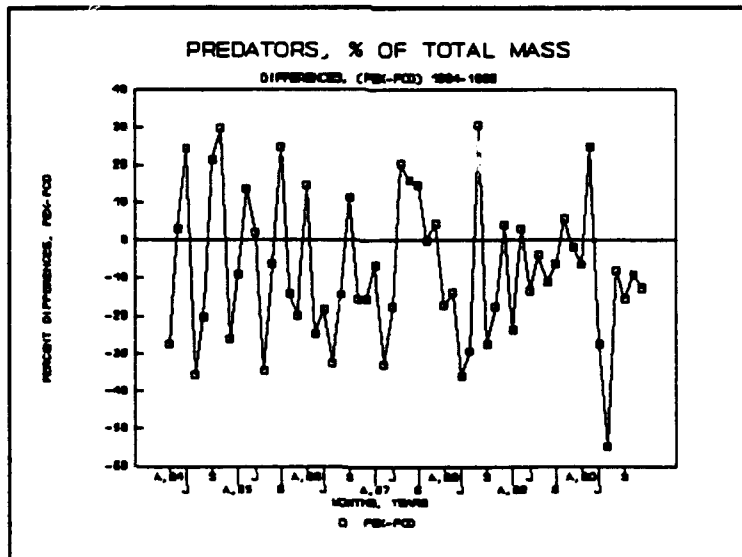


Figure 4.17B. Percent differences between predators/total mass at FEX minus those at FCD. April-November, 1984 - 1990.

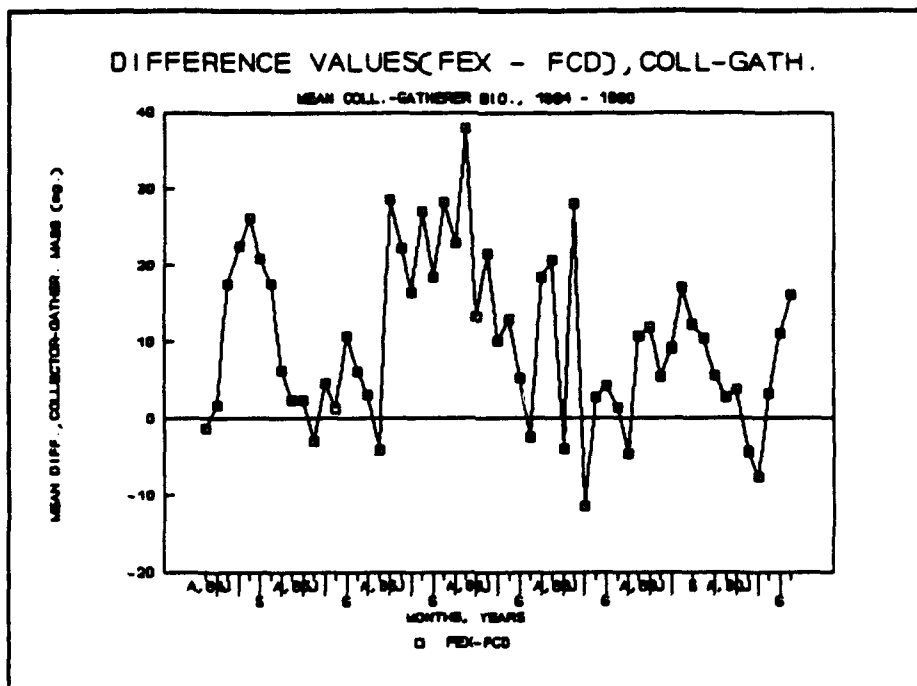


Figure 4.18A. Differences between mean collector-gatherers (mg.). FEX minus FCD. April - Nov., 1984-1990.

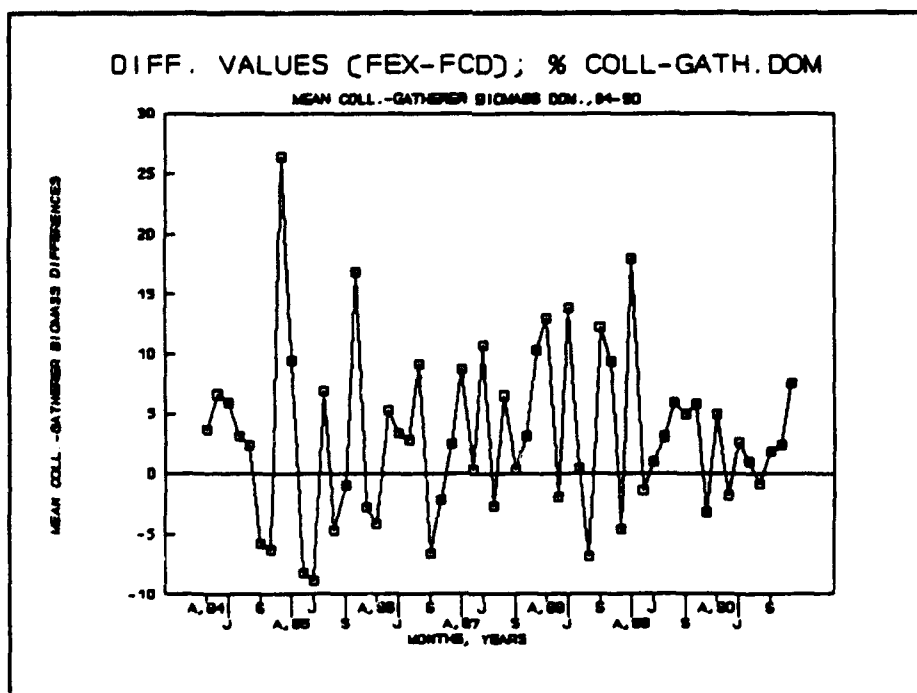


Figure 4.18A. Percent difference between coll.gatherers/total mass at FEX minus those at FCD. Ap-Nov.84-90.

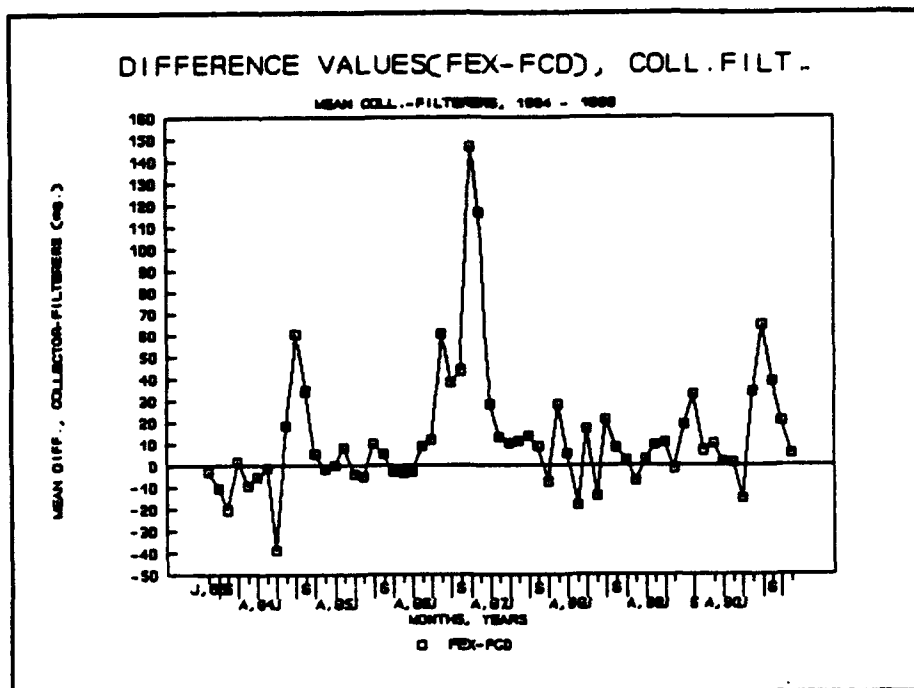


Figure 4.19A. Differences between mean collector-filterers/total mass (mg.). FEX minus FCD. April-November, 1984-90.

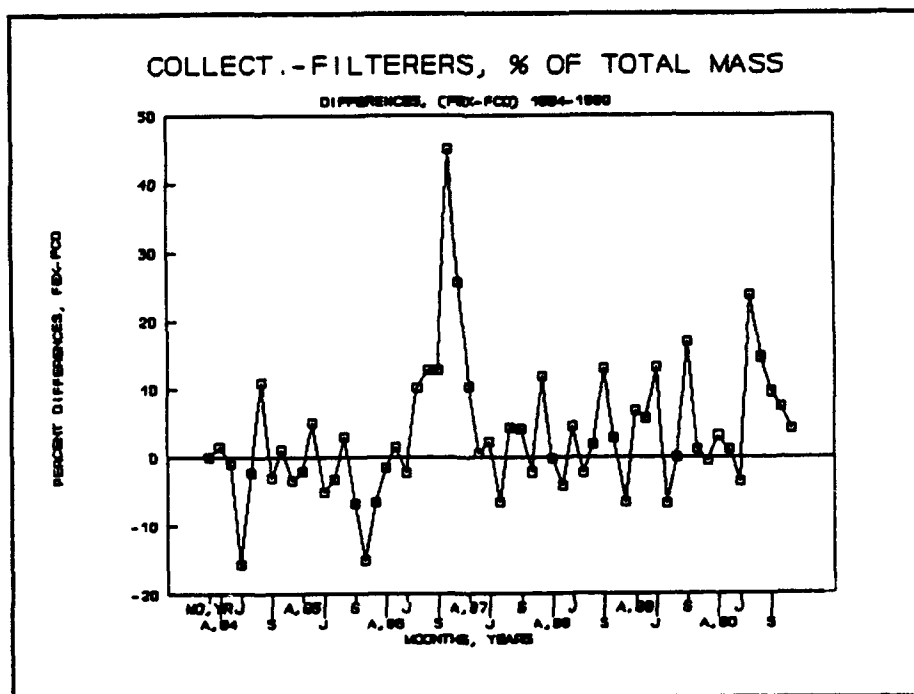


Figure 4.19B. Percent difference between collector-filterers/total mass (mg.) at FEX minus that at FCD. April - Nov., 1984 - 1990.

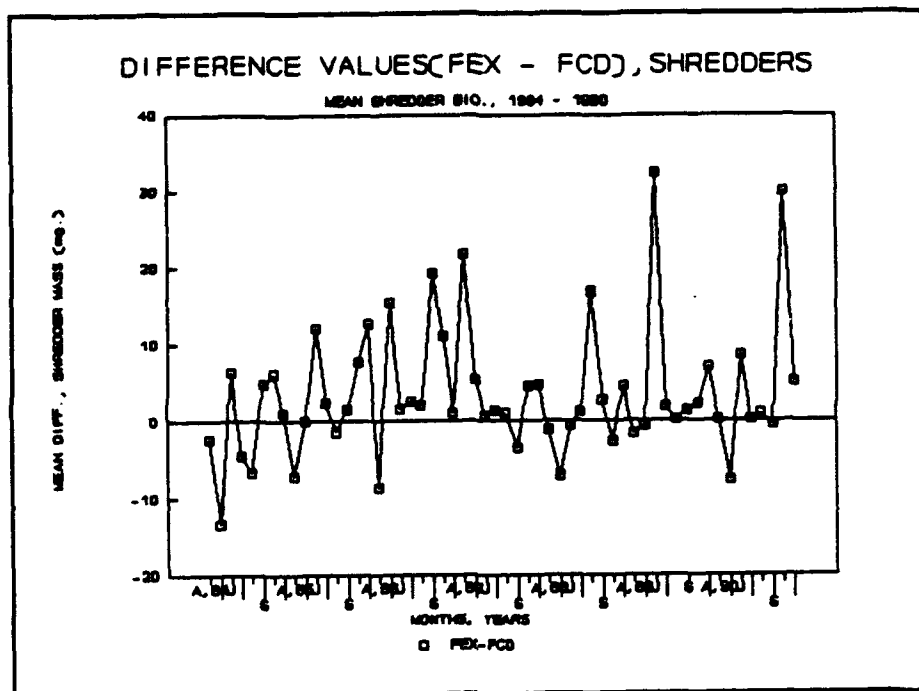


Figure 4.20A. Differences between mean shredders (mg.). FEX minus FCD. April - November, 1984 - 1990.

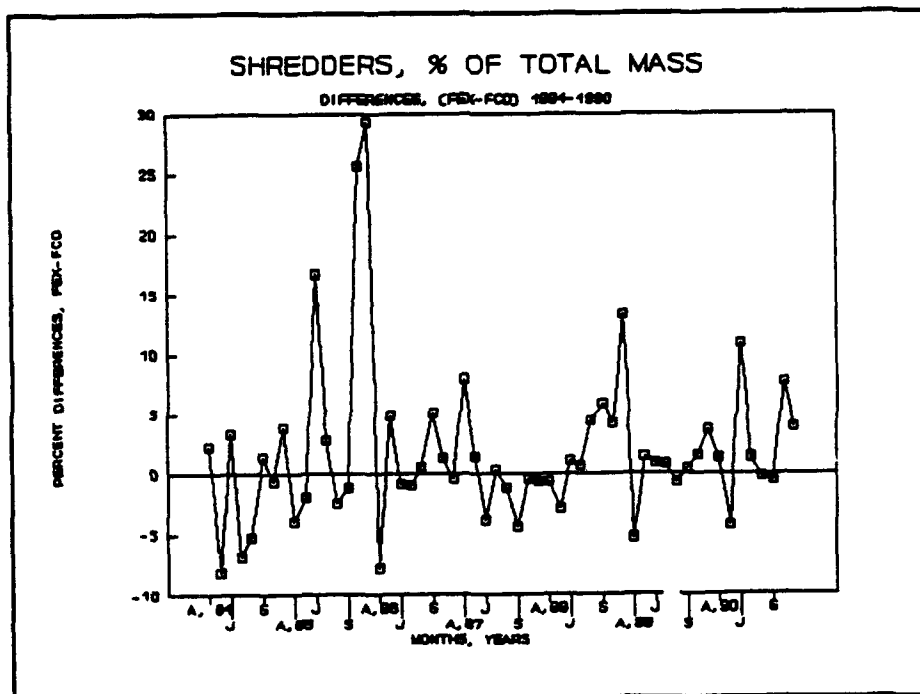


Figure 4.20B. Percent difference between shredders/total mass at FEX minus that at FCD. April-Nov., 1984-1990.

When biomass values of functional feeding groups are first related to the total mass for the sample from which they are derived, the differences between FEX and FCD are reduced (compare Figures 4.17B through 4.20B with Figures 4.17A through 4.20A). Total insect mass at FEX is usually higher than at FCD, but the proportion of functional feeding groups, relative to total mass, is more similar between the sites. Therefore, statistical analyses drew from dominance (or percent of total mass) data.

As shown for structural community parameters, chironomids comprise a large portion of the insects in samples at both sites. The biomass of chironomids as individuals is small; however, the numbers of chironomids are large enough that, often, a large proportion of the mass is attributable to that family. In this report, chironomid biomass dominance was also added to the analysis. Figure 4.21 shows the difference between the two sites in terms of percent dominance, by biomass, of that group.

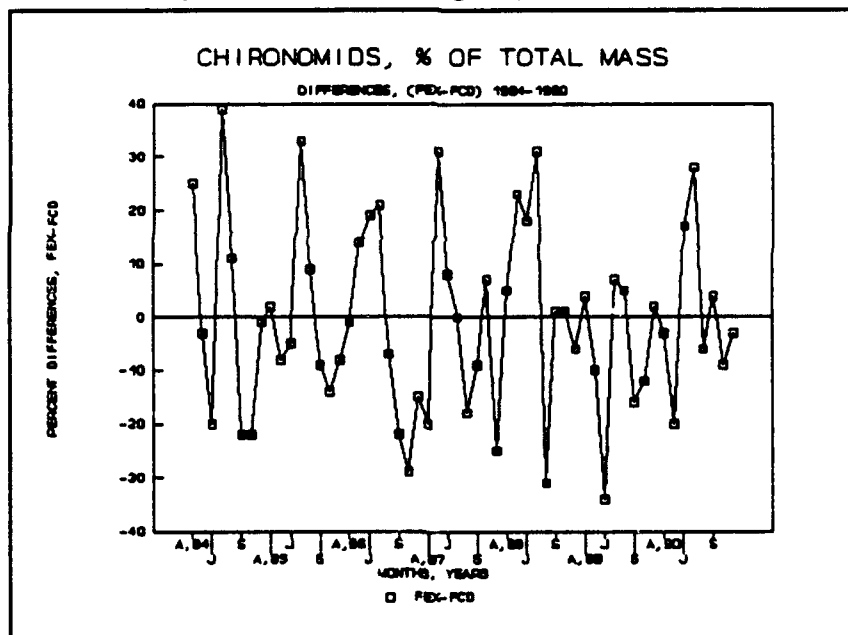


Figure 4.21. Percent difference between chironomids/total mass. FEX minus FCD. April - November, 1984 - 1990.

Peak differences where FEX values were high often occurred in July of each year. FCD values were often higher in the fall. These patterns occurred over the seven years (before and after ELF activation).

Another parameter, which is biologically meaningful in community analyses, is the relationship between predators and their prey (Figure 4.22).

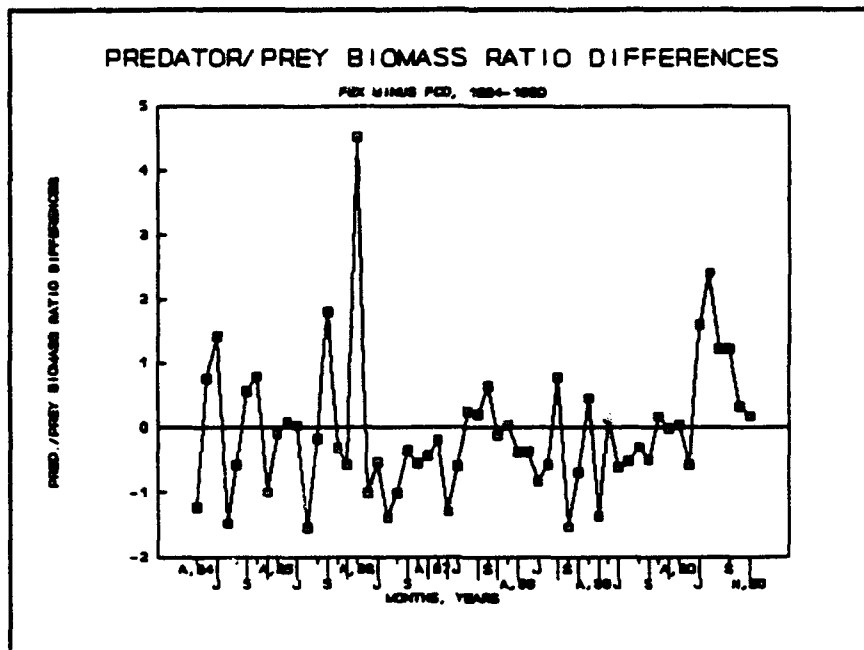


Figure 4.22. Predator/Prey ratio differences; FEX minus FCD. April - November 1984 - 1990.

Until 1990, predator/prey mass ratios between the sites oscillated around the zero point with one major exception. In April of 1986, many dragonflies and predatory stoneflies were taken from samples at FEX. In the summer of 1990, more predators relative to their potential prey were collected at FEX (Figure 4.22). Figures 4.16 and 4.17 show, however, that those samples were very low in total mass and in predator mass. Thus, of the total mass at FEX in those months, a high proportion were predators.

Four functional feeding group parameters were used for statistical analysis: Total mass, percent chironomid dominance, percent collector-gatherer dominance, and predator/prey ratios. The data were separated into seasons to determine statistical patterns based on naturally grouped data. By grouping the data into seasons, several patterns emerged that had been obscured when the months were separate (See 3-Way ANOVAS, 1990 Annual Report, p. 216, 221). Two-Way ANOVA tests for the seasonal data appear in Table 4.7. In only two cases of the possible 12 were there significant interactions between site and year (total mass in the fall and predator/prey ratios in the summer).

Total mass was not significant for year or site differences in the summer months, which have the lowest coefficient of variation values (Figure 4.15B).

TABLE 4.7
2-Way ANOVA Tests for Seasonal Differences, FEX vs. FCD
Functional Community Parameters, WITH CHIRONOMIDS
F VALUES, LEVELS OF SIGNIFICANCE

PARAMETER, SOURCE	D.F.	SPRING	SUMMER	FALL
TOTAL MASS				
Site	1	3.01 n.s.	0.70 n.s.	20.35 ***
Year	6	7.01 ***	1.00 n.s.	15.78 ***
Site, Year	6	0.90 n.s.	1.02 n.s.	4.27 ***
COLL-GATHERER DOMINANCE				
Site	1	6.57 *	7.98 **	8.63 **
Year	6	2.88 *	5.96 ***	4.14 ***
Site, Year	6	0.68 n.s.	1.00 n.s.	0.68 n.s.
CHIRONOMID DOMINANCE				
Site	1	0.40 n.s.	4.41 *	6.77 *
Year	6	2.46 *	1.56 n.s.	8.04 ***
Site, Year	6	0.29 n.s.	0.99 n.s.	1.87 n.s.
PREDATOR/PREY RATIO				
Site	1	6.86 *	23.15 ***	3.08 n.s.
Year	6	1.62 n.s.	3.50 **	5.33 ***
Site, Year	6	1.88 n.s.	2.39 *	1.89 n.s.

$p < .05 = *$; $p < .01 = **$; $p < .001 = ***$

ERROR DEGREES OF FREEDOM 126 196 196

In the spring months of 1986 and 1987 total mass of insects was higher than for spring in other years. This was reflected in year differences for the spring months. During the summer months, the site differences and year

differences were not significant. It is during these times that total insect mass is usually at its highest. As for structural community parameter data, total insect mass fluctuated between sites and among years during the fall. Total mass was usually much higher at FEX than at FCD (Figure 4.16). Some years the differences were high (1985, 1986) and some years they were small (1985, 1987, 1988). There appears to be no consistent pattern relative to ELF activation. Had the fall data been incorporated into the spring and summer analyses, it is probable that all main effects and interaction terms would have been significant.

Although collector-gatherer dominance data had no significant interaction terms for each of the three seasons, there were significant site effects and year effects. Values for this parameter oscillate within seasons each year, and the year to year differences diminish over time (Figure 4.19B).

Chironomid dominance was higher at FEX in the summer season, but higher at FCD in the fall (Figure 4.21), resulting in significant site effects for those two seasons (Table 4.7). In the summer, the differences between the two sites that had been large and usually higher at FEX diminished over the years. In the fall season, FCD usually had the highest chironomid dominance, but over the years, dominance began to approach that of FEX.

In the summer, predator-prey ratios were usually higher at FCD than at FEX, but in 1990 they were always higher (Figure 4.22), probably accounting for the significance for all terms (Table 4.7). The ratios oscillated equally between FEX and FCD; however, in the fall three months of 1986 and 1990 they were higher at FEX.

Physical Factors as Related to Functional Community Variables

Discharge and water temperature were shown to be related to structural community variables, and was expected to be related to functional community variables as well. Table 4.8 gives correlation coefficient (CC) values among insect mass, diatom density, discharge and water temperatures from October 1983 through October 1990. (November through March data each year are usually excluded, as discharge data were normally lacking during those times.) Both discharge and water temperatures were significantly correlated with insect mass. Those physical factors were also correlated with diatom density, but at a lower CC value.

TABLE 4.8
Correlation Coefficients for Biological
and Physical Parameters from October 1983
through October, 1990.

	Ln Perif. Density No/M2 X 10 ⁻⁸	Ln Insect Biomass mg X 10 ⁻¹	Water Temp. °C.	Discharge Rate M3/Sec.
Ln Perif.	1.00			
Ln Insect	.54	1.00		
Water	.35	.56	1.00	
Discharge	-.37	-.53	-.44	1.00
Critical value (1-tail, .05) = ± 0.22				
Critical value (2-tail, .05) = ± 0.26				

Figure 4.23A shows a regression of discharge versus ln of the total insect mass x 10⁻¹. In Figure 4.23B, the dependent variable is periphyton density.

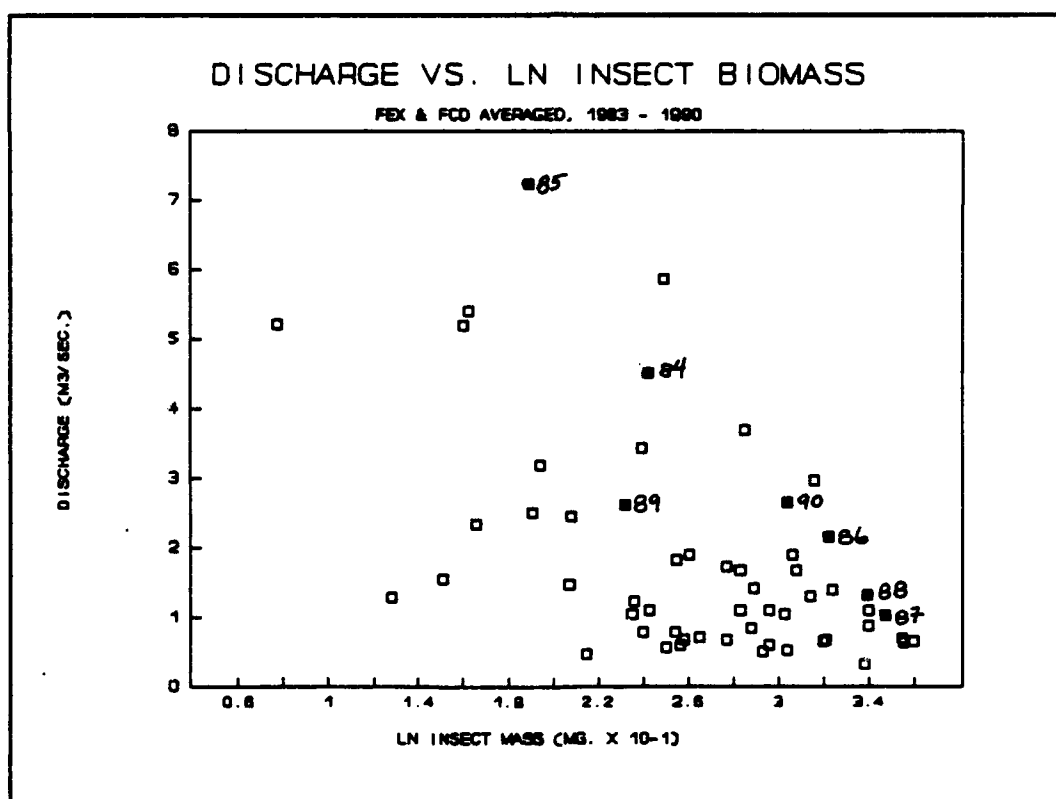


Figure 4.23A. Discharge vs. Ln of mean insect mass (X 10⁻¹). July 1983 - Oct. 1990. Black squares: May of each year

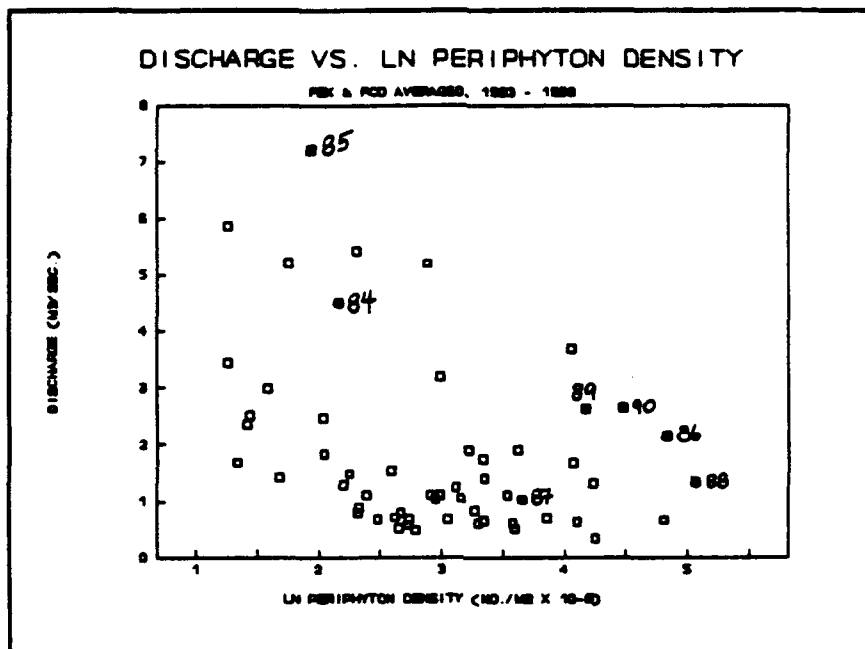


Figure 4.23B. Discharge vs. Ln Periphyton Density (No./M² X 10⁻⁴), both sites combined. July 1983 - Oct., 1990. Black squares: May of each year.

Figures 4.23A and 4.23B show the negative relationship between discharge rate and insect biomass, and between discharge rate and periphyton density. May is a month when both insect biomass and periphyton density have a potential for being high. However, discharge intensities can fluctuate during that month, depending on past snow cover and the timing of the influx of melt waters. For those reasons May values for each year are marked. A regression of discharge versus ln insect mass for May of each year showed a highly significant relationship ($F_{1,8}$ value: 18.82, $p < .001$), with an r^2 of 0.790. Discharge values in the spring, namely May, appears to be a very good index for predicting insect mass in the Ford River. The relationship between discharge and periphyton density is also significant for the month of May: $F_{1,8}$ value: -3.30, $p = 0.2$; $r^2 = 0.685$.

Because ln total insect mass was correlated with mean discharge values, ANCOVAs were performed, using discharge as the covariate and total insect mass as the variate (Table 4.9). These analyses were performed for the spring, summer, and fall months separately.

TABLE 4.9

ANCOVAS for Total Insect Mass (mg.) and
Mean Discharge (m³/sec). Spring, Summer, Fall
1984 - 1990

Season, Source	d.f.	SS	MS	F, sign.
SPRING				
Diff. between adj. means				
Adj. Means	1	1.0581	1.0581	1.377 ns.
Error	137	105.2675	.7684	
Diff. between slopes				
Slopes	1	3.2736	3.2736	4.365*
Sum group dev.	116	101.9938	.7500	
			Common slope: -.3713	
FCD slope: -.254				
FEX slope: -.476				

SUMMER				
Diff. between adj. means				
Adj. Means	1	5.1296	5.1296	13.51***
Error	207	78.5693	.3796	
Diff. between slopes				
Slopes	1	.0146	.0146	0.38 ns.
Sum group dev.	206	78.5548	.3813	
			Common slope: -.4124	

FALL				
Diff. between adj. means				
Adj. Means	1	10.4100	10.4100	22.075***
Error	187	88.1850	.4716	
Diff. between slopes				
Slopes	1	.0083	.0083	.02 ns.
Sum group dev.	186	88.1767	.4741	
			Common slope: -.3541	

ANCOVAS showed that the spring months differed from the summer and fall months. In the spring, the adjusted mean values between the sites did not differ, but the slopes differed significantly. With increasing discharge (up to 6.27 m³/sec), responses to insect mass loss differed between sites; more mass was lost at FEX (Table 4.9, Spring). During the summers, mean discharge values never exceeded 4.56 m³/sec. In that season insect mass

at FEX was higher than at FCD, resulting in a significantly higher adjusted mean value at FEX. The fall period showed the same pattern as the summer period. There were no slope differences between sites during the summer and fall months, indicating that although insect mass was higher at FEX, insect responses to discharge at each site were similar.

Multiple regressions were performed for each site on total mass, percent biomass dominance by chironomids, percent biomass dominance by collector-gatherers, and predator/prey ratios. The independent physical variables were years, ELF ground field cumulative exposure, discharge, and cumulative degree days. The data were grouped season by season (Tables 4.10, 4.11, and 4.12). Percent data for the dependent parameters were transformed (arc sine of square root of $Y/100$) and the ratio data were transformed (arc sine of square root of Y).

TABLE 4.10
Multiple Regressions for Biotic Parameters versus
Years, E.L.F. Cumulative Exposure, Discharge, and Cumulative Degree Days
Spring (1987 - 1990)

Dependent Variables, R^2 and F values

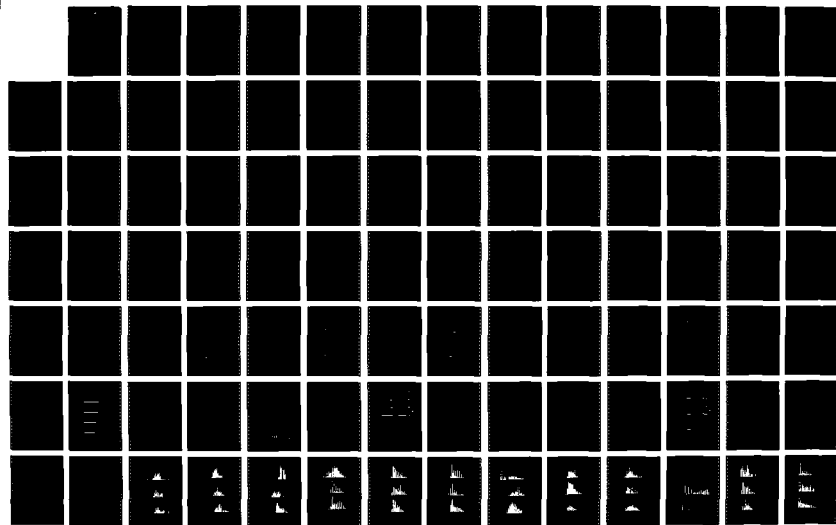
<i>Independent Vars.</i>	<i>Total Mass</i>	<i>% Chiro Dom.</i>	<i>% C-G Dom.</i>	<i>Pred/Prey R.</i>
FEX				
R^2	.320	.387	.178	.079
Years	0.060	1.354	0.215	0.003
ELF	0.003	2.110	0.067	0.001
Discharge	16.241	2.058	0.477	3.264
Cum.D.Days	4.135	3.897	8.643	0.305
FCD				
R^2	.378	.123	.068	.223
Years	0.958	3.130	1.992	1.833
ELF	0.100	2.114	1.373	0.436
Discharge	23.443	0.461	0.149	6.956
Cum.D.Days	0.018	2.120	0.018	0.092

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Spring: The coefficient of multiple regression values were all below .400 for the spring data (Table 4.10). F-values were high for discharge for total mass and for predator-prey ratios at both sites. Previous analyses (Tables 4.8, 4.9) have shown that total mass was highly correlated with discharge.

TABLE 4.11
Multiple Regressions for Biotic Parameters versus
Years, E.L.F. Cumulative Exposure, Discharge, and Cumulative Degree Days
Summer (1986 - 1990)

Dependent Variables, R² and F values

<i>Independent Vars.</i>	<i>Total Mass</i>	<i>% Chiro Dom.</i>	<i>% C-G Dom.</i>	<i>Pred/Prey R.</i>
FEX				
R²	.416	.141	.303	.187
Years	0.146	0.015	15.096	4.408
ELF	0.754	0.186	9.399	3.748
Discharge	14.080	5.257	12.553	2.188
Cum.D.Days	0.118	3.970	20.564	13.606
FCD				
R²	.691	.157	.051	.065
Years	6.528	1.059	0.174	0.144
ELF	4.268	0.526	0.577	0.001
Discharge	40.766	8.587	0.197	0.067
Cum.D.Days	7.998	4.904	0.013	1.028
BOLDFACE IF R² > 0.50				

Summer: Discharge and/or cumulative degree days accounted for most of the variation in total insect mass and percent biomass chironomid dominance (Table 4.11). ELF cumulative degree days accounted for an insignificant amount of the variance.

Table 4.12 presents the data for the fall season, where there is often high variability in the biological parameters.

TABLE 4.12
Multiple Regressions for Biotic Parameters versus
Years, E.L.F. Cumulative Exposure, Discharge, Cumulative Degree Days
Fall (1986 - 1990)

Dependent Variables, R² and F values

<i>Independent Vars.</i>	<i>Total Mass</i>	<i>% Chiro Dom.</i>	<i>% C-G Dom.</i>	<i>Pred/ Prey R.</i>
FEX				
R²	.621	.185	.064	.0957
Years	0.248	0.110	2.277	5.536
ELF	3.286	0.302	2.077	3.730
Discharge	0.455	2.833	2.807	1.312
Cum.D.Days	21.503	7.804	3.628	0.349
FCD				
R²	.101	.185	.076	.112
Years	3.957	0.110	0.770	3.623
ELF	3.543	0.302	0.277	2.372
Discharge	0.6386	2.833	1.065	0.878
Cum.D.Days	0.250	7.804	1.316	0.717
BOLDFACE IF R² > 0.50				

Fall: Only once was the R² value above .500 and that was for total mass at FEX, where cumulative degree days accounted for most of the variation. For the other biotic parameters, cumulative degree days also accounted for much of the little variation accrued by the dependent parameters.

In summary, discharge was the 'most important' dependent variable for the spring functional community parameters; discharge and cumulative degrees for the summer; and cumulative degree days for the fall data set. Overall results for structural community parameters were the same.

The multiple regression tests included only data after ELF activation. In order to determine whether there were differences before versus after ELF activation, B.A.C.I. tests were performed on mean total insect mass, percent

chironomid biomass dominance, percent collector-gatherer biomass dominance, and predator/prey ratios. The data were separated into seasons for the analyses (Table 4.13).

TABLE 4.13
Results of B.A.C.I. Comparisons for Functional Community Parameters
at FEX vs. FCD. Spring, Summer, Fall

Spring BEFORE: 1984-1986, AFTER: 1987-1989
Summer BEFORE: 1984-1985, AFTER: 1986-1989
Fall BEFORE: 1983-1985, AFTER: 1986-1989

Index, Comparison	Trans- form Type	Tukey's Test for Additivity		t-test, Signif.	
		df.	F-value, sig.	df.	T-value sig.
TOTAL MASS					
Spring	LOG(X+1)	4	2.41	12	-0.039
Summer	LOG	4	7.70	19	-0.269
Fall	LOG(X+1)	7	3.63	25	0.202
% CHIRONOMID DOMINANCE					
Spring	RATIO	4	2.05	12	-0.140
Summer	RATIO	4	3.66	19	0.429
Fall	Arcsin	7	1.39	25	-0.598
% COLLECTOR-GATHER DOMINANCE					
Spring	RATIO	4	2.73	12	1.985
Summer	RATIO	4	2.32	19	-0.974
Fall	RATIO	7	3.25	25	0.345
PREDATOR/PREY RATIOS					
Spring	LOG(X+1)	4	6.73	12	0.936
Summer	LOG(X+1)	4	0.72	19	0.679
Fall	LOG(X+1)	7	0.64	25	1.122

All parameters passed Tukey's test for additivity, and there were no before versus after differences for all four biotic parameters during the spring, summer and fall periods. Although there were significant differences in some cases for these parameters when all the replicates were used in 2-Way ANOVA tests (Table 4.7), BACI tests revealed no significant differences before as compared with after ELF activation. Multiple regression analyses, using

after ELF activation years, showed that any relationships between the biotic parameters and physical parameters were non-ELF in nature. In summary, physical factors such as discharge and water cumulative degree days accounted for most of the variability after ELF activation (Tables 4.10 - 4.12).

Changes in Mean Dry Weights Per Individual:

Six species were selected for studies on changes in MDW/IND values: three collector-gatherer mayflies, Paraleptophlebia mollis, Ephemerella invaria, and Ephemerella subvaria; two collector-grazer caddisflies, Glossosoma nigrior and Protoptila sp.; and one coleopteran, Optioservus sp. (Samples were collected mid-month each year. They were collected within five days of each other for each month every year.).

Figures 4.24A and 4.24B show changes in MDW/IND for E. invaria and E. subvaria.

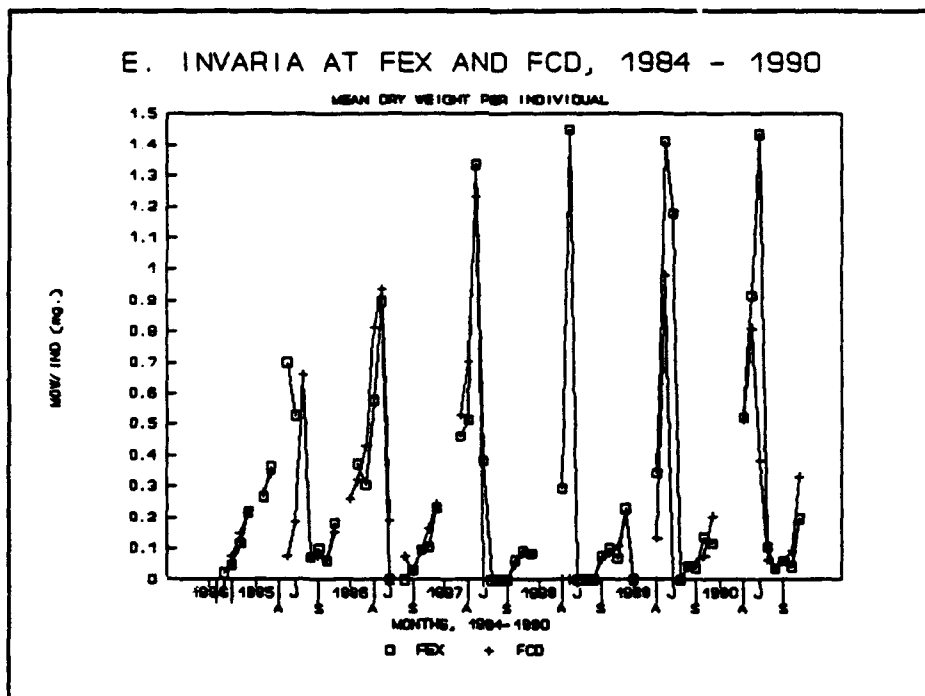


Figure 4.24A. Changes in MDW/IND values for Ephemerella invaria at FEX (squares) and FCD (pluses). June 1984 - November 1990.

Ephemerella invaria is most abundant in the early fall when its MDW/IND value is low. It is univoltine, with its major emergence being in late spring. It is only half the size of its sister species, E. subvaria. We collect samples once a month, and we collected the final instars of E. invaria in May of 1987, 1988 and 1989. Graphical analysis (Figure 4.24A) does not reveal differences in emergence times after ELF activation. The gaps in this figure are owing to the fact that we no longer sample in December through March each year. Ephemerella subvaria is less common than is E. invaria, and therefore, there are more gaps in Figure 4.24B. However, it is possible to see the major emergence periods for this univoltine species. Its major peaks were in May of 1987 and in June of 1988 and 1989.

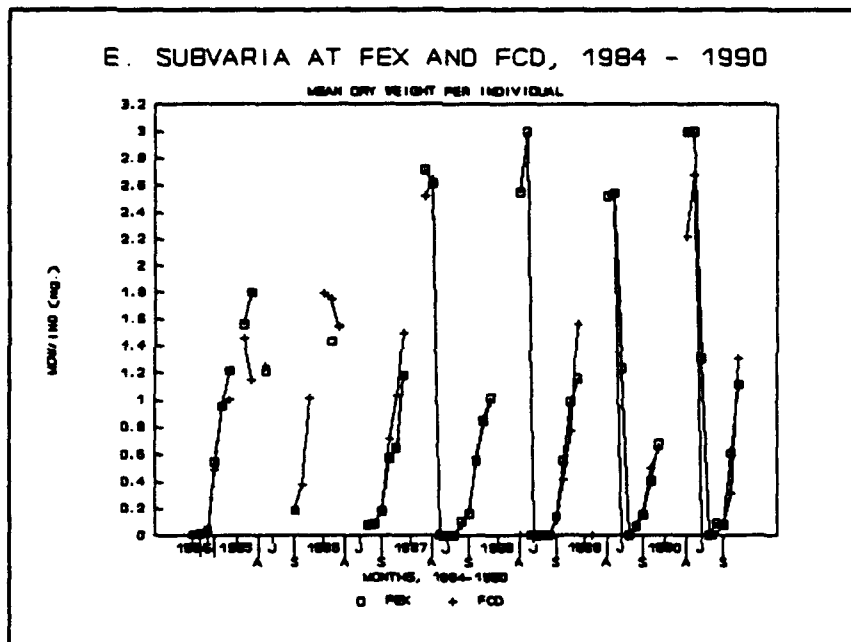


Figure 4.24B. Changes in MDW/IND values for Ephemerella subvaria at FEX (squares) and FCD (pluses). June 1984 - November 1990.

Paraleptophlebia mollis has very regular emergence patterns. It is also very common at both sites throughout the year. This species best fulfills our criteria of a univoltine and numerically abundant species, Figure 4.25A.

Figure 4.25B shows changes in MDW/IND values according to cumulative degree days. By presenting the data in this manner, it is possible to more easily see whether the peaks in individual biomass were found at each site. More importantly, we can see the number of cumulative degree days it took to achieve a certain size class at each site. If ELF seriously affected numerical

abundance, seasonal growth patterns, and/or emergence patterns of this species, we should be able to detect changes more easily, using cumulative degree days.

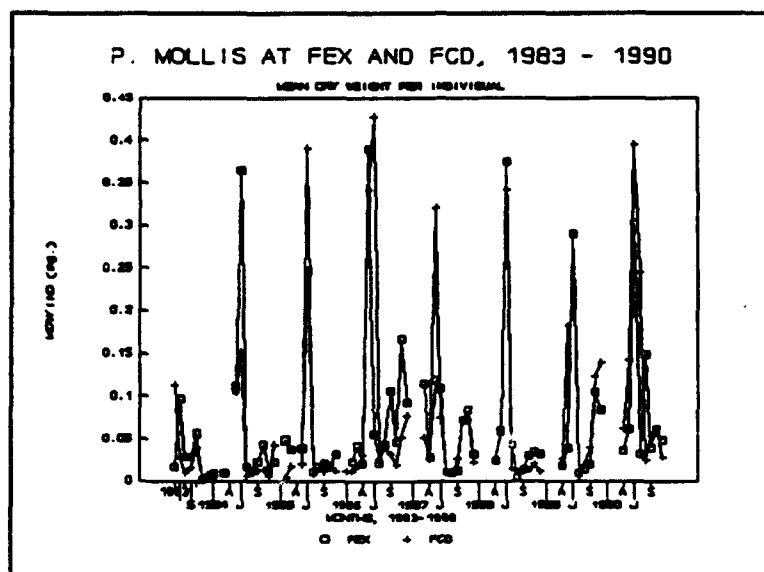


Figure 4.25A. Changes in MDW/IND values for *Paraleptophlebia mollis* at FEX (squares) and FCD (pluses). November 1983 to November 1990.

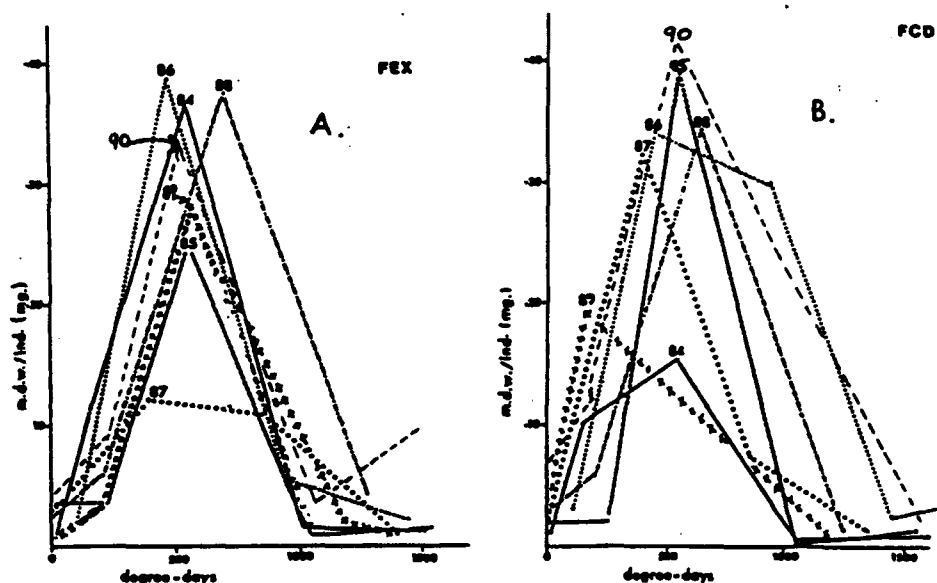


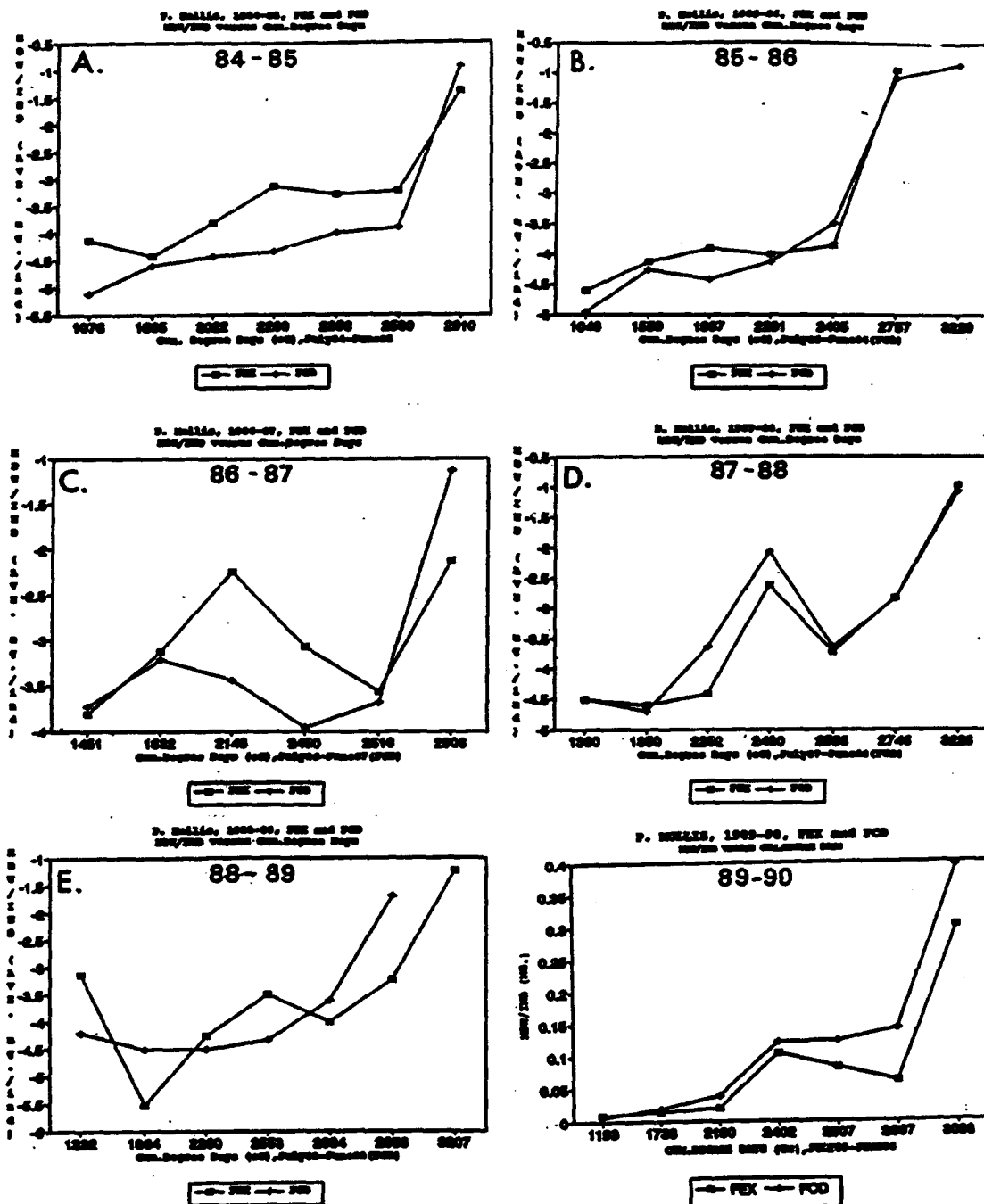
Figure 4.25B. Changes in MDW/IND values for *P. mollis* versus cumulative degree days. FEX: first panel; FCD: second panel. April - July from 1984 through 1990.

Figures 4.26A through 4.26F show plots of growth rates (as estimated from \ln MDW/IND values) versus cumulative degree days at each site from 1984-85 through 1989-90. In 1984 through 1986 there was a steady increase in growth rates for the species at both sites, with maximum growth occurring between May and June each year. In the following years, for the most part, there were spurts of growth during the fall. Figure 4.26C shows a decided increase in growth between August and September at FEX; Figure 4.26D shows increases in growth rates between September and November; Figure 4.26E shows an increase from August through October at FEX. Figure 4.26F, 1989-1990 data, shows an increase in October at both sites.

The decided decreases in MDW/IND values from September or November to April may be owing to several factors, none of which appear to be ELF-related. There could be size-selected predation of this species by insectivorous fish during those mild winters when *P. mollis* increased in size. Or there could be differential losses in the larger size classes during spring floods. Finally, there could be sampling error problems ($n = 5$). In any case the overall patterns between FEX and FCD for this species are very similar. These growth rates cannot be linearized by any transform, including the \ln transform. Although there is year-to-year variability, sites each year are similar, and we suggest that there were no ELF effects for this species.

Protoptila sp. is most common during the mid-summer (Figure 4.22A, 1990 Annual Report, p. 233), just after emergence in mid-May (Figure 4.27, this report) of the prior year's young. In 1989, there were heavy rains in late May and June, which we feel contributed to the low numbers of individuals and the lack of large individuals during that time. Numbers of individuals will be compared at the two sites to see whether there were any differences among the years. We feel we have 'captured' too few large-sized individuals; therefore, analyses of changes in MDW/IND values may be impossible.

Glossosoma nigrior, which is in the same family as *Protoptila* and is a collector-grazer, is most abundant at FEX (Figure 4.23A, 1990 Annual Report, p. 234). The numbers of individuals at the two sites occurring in the summer seasons; peak size occurs in May of each year (Figure 4.28, this report). We have found fewer numbers of individuals of this species at the two sites than of *Protoptila* sp. Analyses similar to those for that latter species will be made for *G. nigrior* in future Annual Reports.



Figures 4.26 A,B,C,D,E,F. Ln changes in MDW/IND for *P. mollis* at FEX and FCD from July through the following May or June each year versus cumulative degree-days (°C) at FEX and at FCD. A: 1984-1985; B: 1985-86; C: 1986-87; D: 1987-88; E: 1988-89; F: 1989-90.

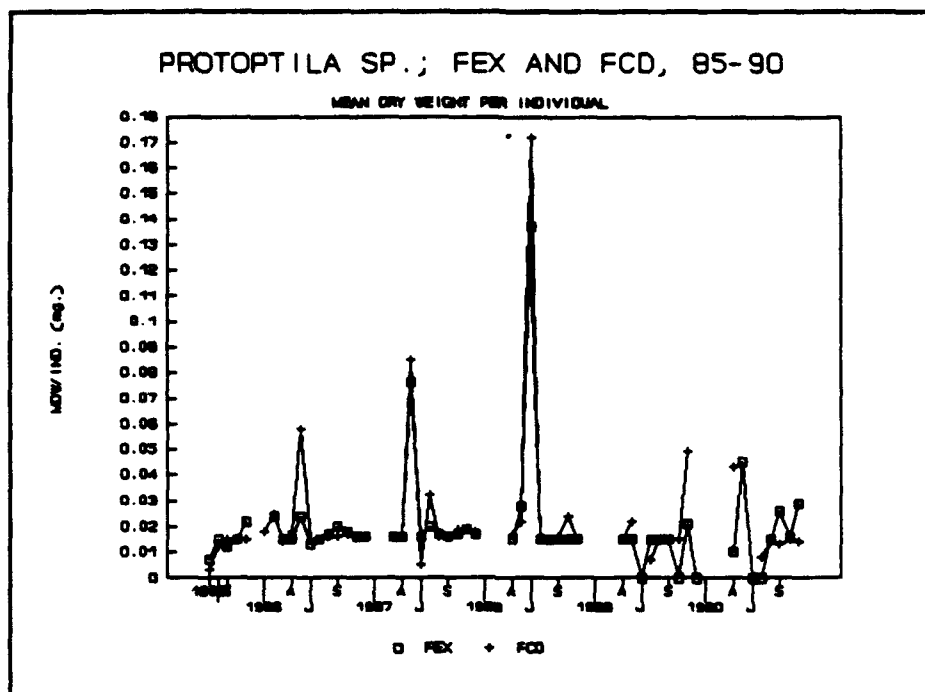


Figure 4.27. Changes in MDW/IND for Protopila sp. at FEX (squares) and FCD (pluses), May 1985 through November 1990.

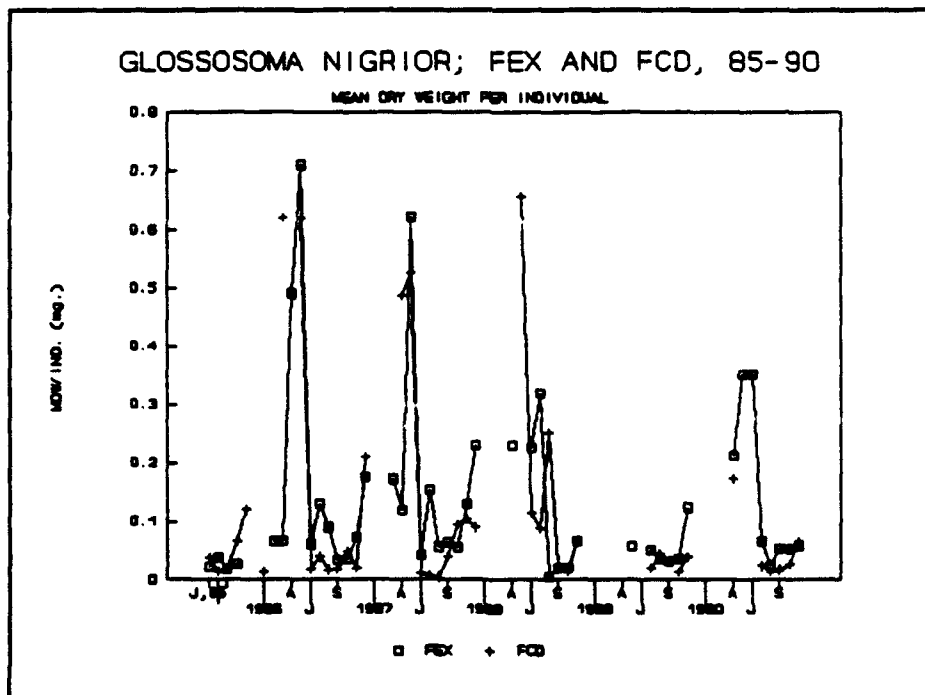


Figure 4.28. Changes in MDW/IND for Glossosoma nigror at FEX (squares) and FCD (pluses), May 1985 through November 1990.

Chironomids were only identified to family level for reasons explained earlier. As there are so many individuals of this family in samples, a plot of changes in MDW/IND values is presented (Figure 4.29). Even though the graph represents size classes of a number of species, there is a general pattern that emerges; i.e., large individuals are more abundant during the summer months and small individuals are more abundant during the fall and early winter months. These seasonal differences probably reflect replacements of summer emerging with fall growing species. If person power and money were no object, it would be a good idea to select at least one species and follow its numbers and growth patterns through the seasons.

In the past Optioservus sp. has been followed for numbers of adults and larvae at each site (Figures 4.21A,B, 1990 Annual Report, p. 232). Numbers are much lower at FEX than at FCD. In the Revised Annual Report, the ratio between adults and nymphs may be analyzed. For the present, there is insufficient time.

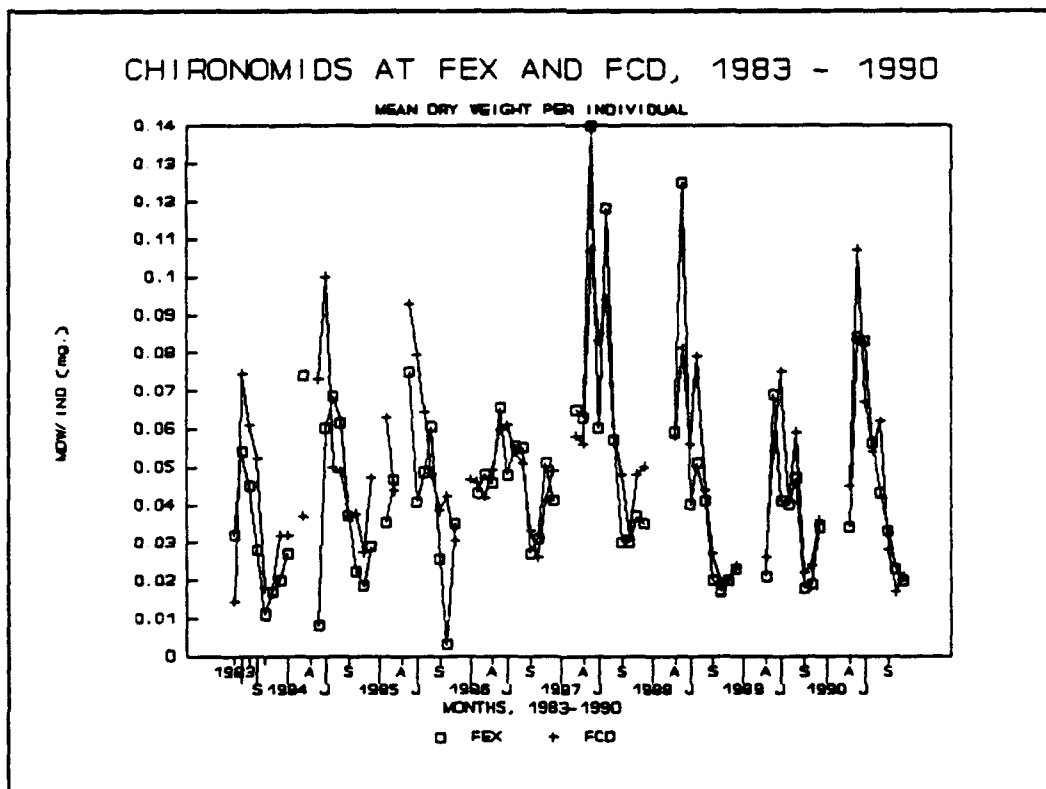


Figure 4.29. Changes in MDW/IND for chironomids at FEX (squares) and FCD (pluses), November 1983 through November 1990.

Submission of the Annual Report occurred two months after identifications of insects in substrates for 1990 were completed. At the writing of the Revised Annual Report, those identifications have now been completed through November of 1991.

Future Plans for This Element

The same design and accumulation of data will continue, including collection of samples from the new site, FEX.LINE, until at least August of 1992 when comparisons among the sites for 1990 and 1991 will be completed. Those analyses will be used to ascertain the statistical utility and value of the new site. Until that time, identification of insects for samples from FEX.LINE will receive the lowest priority.

Analyses for FEX versus FCD comparisons will continue to include 2-Way ANOVAS for analyzing site or year differences and then ANCOVAS and multiple regressions for looking at the relationships between physical and biotic variables. Minimum detectable difference values will be determined for the biotic parameters, season by season. Studies will continue on ELF cumulative exposure values. The three principle investigators for the Aquatics Task Group will discuss their choices for breakpoints in the data relative to ELF activation. As it stands, each of the three groups has selected separate points, ranging from only before versus after ELF activation comparisons to before, transition, and full activation periods. B.A.C.I. tests for before versus after effects may be modified with the help of Dr. Abdul El Shaarowi, as described in the text above. It is hoped that residuals among samples rather than sample means can be used in the analyses to 1) account for sample variance, and 2) to utilize all the data rather than only the means.

Cumulative degree days is an important independent variable for changes in MDW/IND values for the six species studied so degree days as well as chronological time will be continue to be used for determining whether E.L.F. has any effect on changes in growth rates. In addition, changes in numbers of individuals for these species will be analyzed, using 2-Way ANOVAS for seasonally grouped data, and, when appropriate, B.A.C.I. and ANCOVA analyses. Seasonal groupings of those matrices are biologically more meaningful than any other grouping, as determined by coefficient of variation values and by ANCOVAS.

The taxa identified thus far at FEX and at FCD appear in Appendix I of this Report.

Summary

Data were grouped according to season for statistical analyses after looking at coefficient of variation values: spring (April, May), summer (June through August), and fall (September through November) seasons. The lowest coefficient of variation values were during the summer 'stable' periods. Spring and fall seasons are transitional seasons for the insects. Coefficient of variation values were highest during those seasons. Seasonal data were first analyzed, using 2-Way ANOVAS. Then they were independently regressed at each site against years, ELF cumulative exposure, discharge, and water cumulative degree days to determine which physical factors were more important in accounting for the biotic variance. Usually discharge was the most correlated in the spring with the biotic parameters. Discharge and/or cumulative degrees was most important in the summer. Cumulative degree days was the most important independent variable in the fall season.

B.A.C.I. tests were used to look for significant before versus after ELF activation associations. Summer evenness was the parameter showing a significant before versus after effect. An ANCOVA, using discharge as the covariate showed that both mean differences between sites and slope differences between sites were highly significant. It is probable that significant differences for J' before versus after ELF activation were more related to before versus after differences in discharge than to any ELF effect. B.A.C.I. tests were never significant for the four functional community parameters. Discharge was shown to be highly correlated with insect mass and with periphyton density. The linear relationship was even more pronounced for May discharges and insect mass ($r^2 = 0.790$) and May discharges and periphyton density ($r^2 = 0.685$).

Graphical analyses were presented for changes in mean dry weight values per individual for six prominent taxa at the sites. Changes were presented in terms of chronological time, and in one case, physiological time (cumulative degree day water temperatures). Although the yearly growth patterns of Paraleptophlebia mollis differed, within year growth patterns were similar at the experimental and reference sites, indicating that ELF activation did not affect growth rates of this species.

A list of taxa collected at the two sites and on leafpacks appears as Appendix I in this Element. In the 1992 Annual Report, a similarity matrix will be analyzed. A summary table (4.14) gives statistical results for seasonal comparisons of the biotic parameters.

TABLE 4.14

Summary of Statistics for Structural and Functional Community Parameters
 2-Way ANOVAS: 1984-1990, Multiple Regressions: 1986-1990,
 B.A.C.I.: Before: April 1984 - May, 1986, After = June 1986 - November 1990

PARAMETER, SEASON	2-WAY ANOVA: Signif. factors	MULT.REG.: Vars. with high F values	B.A.C.I. Tests
DIVERSITY		When $r^2 > .50$	
Spring	Site, Year		N/A
Summer	Year	FEX: Disch, CDD FCD: ELF, CDD	n.s.
Fall	Site, Year	FEX: CDD	n.s.
EVENNESS			
Spring	Site, Year		N/A
Summer	Year	FEX: CDD, ELF, Disc. FCD: CDD, ELF, Disc	$p < .001$
Fall	Site, Year		n.s.
RICHNESS			
Spring	Site, Year		n.s.
Summer	Site, Year	FEX: Disch, Yr FCD: Disch	n.s.
Fall	Site, Year	FEX: CDD, Yr	n.s.
NO. INDIVIDUALS			
Spring	Site, Year, Interact.	FEX: Disch, ELF; FCD: Discharge	n.s.
Summer	Site, Year, Interact.		N/A
Fall	Site, Year	FEX: CDD	N/A
% DOMINANCE, # CHIRONOMIDS			
Spring	Site, Year, Interact.	FEX: Disch, ELF FCD: Disch, ELF, Yr	n.s.
Summer	Site, Year	FEX: Disch, Yr FCD: Disch	n.s.
Fall	Site, Year	FEX: ELF, CDD	N/A

Table 4.14, continued			
PARAMETER, SEASON	2-WAY ANOVA	MULT.REG.Vars. with high F values	B.A.C.I. Tests
TOTAL INSECT MASS		when $r^2 > .50$	
Spring	Year		n.s.
Summer	All n.s.	FCD: Disch, CDD	n.s.
Fall	Site, Year, Interact	FEX: CDD	n.s.
% DOMINANCE, CHIRONOMID MASS			
Spring	Year		n.s.
Summer	Site		n.s.
Fall	Site, Year		n.s.
% DOMINANCE, COLLECTOR-GATH. MASS			
Spring	Site, Year		n.s.
Summer	Site, Year		n.s.
Fall	Site, Year		n.s.
PREDATOR/PREY RATIO			
Spring	Site		n.s.
Summer	Site, Year, Interact.		n.s.
Fall	Year		n.s.

N/A = failed Tukey's Test for Additivity

Disch = Discharge,
CDD = Cumulative Degree Days,
ELF = ELF Cumulative Exposure,
Yr = Year

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APPENDIX I

List of Aquatic Insect Taxa from the FEX and FCD sites in the Ford River

EPHEMEROPTERA

Tricorythodes
Drunella cornutella
Dannella simplex
Ephemerella invaria
E. needhami
E. rotunda
E. subvaria
Serratella deficiens
S. sordida
Eurylophella bicolor
Baetis flavistriga
B. vagans
B. macdunoughi
B. pygmaeus
Pseudocloeon parvulum
P. punctiventris
Isonychia sp.
Siphonorus rapidus
Paraleptophlebia mollis
Paraleptophlebia debilis
Leptophlebia cupida
Epeorus vitrea
Rhithrogena jejuna
Stenonema vicarium
S. modestum (= S. rubrum)
S. exiguum (= S. quinquespinum)
S. pulchellum
Leucrocuta hebe (= Heptagenia hebe)
Nixe lucidipennis
Stenacron interpunctatum
Baetisca laurentina
Ephemera simulans
Hexagenia limbata

ODONATA

Ophiogomphus colubrinus
O. carolus
Gomphus (Stylurus) scudderi
G. lividus

Dromogomphus spinosus
Hagenius brevistylus
Boyeria vinosa
Cordulegaster maculatus
Calopteryx sp.

PLECOPTERA

Allocapnia
Paracapnia
Capnia
Haploperla
Alloperla
Suwallia
Acroneuria lycorias
A. abnormis
Paragnetina media
Isogenoides
I. olivaceous
Isoperla transmarina
I. slossonae
Amphinemura
Paranemoura
Pteronarcys
Taeniopteryx nivalis

HEMPITERA

Belostoma flumineum
Lethocerus

TRICHOPTERA

Brachycentrus numerosus
Glossosoma intermedium
G. nigrilor
Protoptila tenebrosa
Anabolia
Hydatophylax argus
Platycentropus
Pycnopsyche subfasciata
Neophylax nacatus
Ceratopsyche morosa
C. sparna
Cheumatopsyche analis

Potamyia
Hydroptila
Leucotrichia pictipes
Neotrichia
Oxyethria
Lepidostoma
Oecetis avara
Ceraclea angustus
Triaenodes tarda
Mystacides
Setodes incertus
Psilotreta indecisa
Molanna
Chimarra aterrima
Dolophilodes distinctus
Ptilostomis
Neureclipsis crepuscularis
Nyctiophylax moestus
Psychomyia flavida
Lype diversa
Helicopsyche borealis

COLEOPTERA

Ancyronyx variegata
Optioservus
O. fastiditus
O. trivittatus
Macronychus glabratus
Dubiraphia
Helichus lithophilus
Gyrinus
Celina
Dytiscus harrisi
Laccophilus
Paracymus subcupreus

MEGALOPTERA

Nigronia
Sialis

DIPTERA

DOLICHOPODIDAE

Rhaphium

EMPIDIDAE

Hemerodromia

Clinocera

Chelifera

BLEPHARICERIDAE

Blepharicera

TABANIDAE

Tabanus

Chrysops

TIPULIDAE

Antocha

Tipula

T. abdominalis

Hexatoma spinosa

Dicranota

Hesperoconopa

CERATOPOGONIIDAE

Probezzia

Culicoides

CHIRONOMIDAE

Tanytarsus

Rheotanytarsus

Microspectra

Stempellinella

Stempellina

Ablabesymia

Pentaneura

Thienemannimyia

Labrundina

Procladius

Procladius cf. sublettei
Nilotanypus
Brillia flavifrons
Parametriocnemus
Corynoneura
Eukiefferiella
E. devonica
E. claripennis
Rheocricotopus
Cricotopus
Thienemanniella
Synorthocladius
Orthocladius
Tventenia bavarica group
T. discoloripes
Diplocladius
Lopescladius
Nannocladius
Chaetocladius
Symposiocladius
Heterotrissocladius marcidus
Xylotopus par
Polypedilum lonvictum
P. scalaenum
P. halterale
P. aviceps
Robackia
R. demeijerei
Microtendipes
Stenochironomus
Cryptochironomus
Saetheria
Parachironomus
Chironomus
Cryptotendipes
Xenochironomus
Paraleuterborniella
Potthastia
Pagastia

ATHERICIDAE

Atherix variegata

SIMULIIDAE

Cnephia mutata

Simulium euryadminiculum

S. corbis

S. quebecense

S. venustum

S. rugglesi

S. jenningsi

S. tuberosum

Prosimulium mixtum

P. mysticum

Ectemnia invenusta

Element 6 - Leaf Litter Processing

Changes from the Work Plan - Added a new site, FEX.LINE, to increase the differential between E.L.F. fields at an experimental site and FCD.

Objectives

1) To quantify leaf processing rates for fresh and autumn abscised speckled (tag) alder leaves (*Alnus rugosa*) each year to see whether leaf processing rates differ as a function of E.L.F. fields; 2) to determine structural and functional community indices for insects colonizing tag alder leaves for subsequent analyses as to E.L.F. effects; 3) to measure growth rates (changes in mean dry weights per individual) for two species of mayflies and one species of stonefly each year to see whether E.L.F. affects growth rates.

Rationale

Processing rates of leaves incorporate the functional responses of fungi, bacteria, protozoans and leaf feeding invertebrates, especially shredding insects (Cummins et al. 1989, Petersen and Cummins 1974, Stout and Taft 1985). E.L.F. fields may influence some of those processors with regard to orientation, activity, or both, as many aquatic plant and animal species contain magnetite crystals (Kirschvink 1989). Some of these species, including freshwater bacteria and algae, are magnetotactic, (Tenforde 1989). It is conceivable that some aquatic species in the Ford River respond to E.L.F. fields as well as to other geomagnetic fields. If so, not only might their activities or growth rates be altered, but leaf processing rates, the resultant sum of their activities, may also be altered.

Many non-anthropogenic environmental factors can affect leaf processing rates: water temperature and flow rates (Kaushik and Hynes 1971), leaf chemistry (Iverson 1974, Stout 1989), and beaver activity (Naiman et al. 1984) may all play a role in the Ford River. Some of these factors may override any E.L.F. effects (see Tenforde 1989) or some E.L.F. perturbations may themselves "...be within the ranges of disturbances that a system can experience and still function properly." (O.T.A. 1989). In either case, any potential E.L.F. effects may or may not be detectable even though coefficient of variation values for many biotic parameters are very low for this Element.

A number of anthropogenic factors can also affect leaf processing rates and colonization of insects on those leaves. Examples include chemical inputs (Fairchild et al. 1984, Stout and Cooper 1983, Cairns 1985), thermal stress associated with impoundments and commercial industries (Gersick and Brusven 1981), and forest alterations (Webster and Waide 1982). As E.L.F. fields appear to be an anthropogenic phenomenon for which there is no analog, the foundations for decisions as to which factors may most strongly affect any given organism -- intensity, duration, transient behavior -- are poorly understood (O.T.A. 1989). This problem is especially critical when studying potential effects under field conditions, where several non-anthropogenic and anthropogenic factors may interact. Considering these uncertainties, the continual monitoring of biological parameters that show low variation in time and space is the most pragmatic approach for detecting any E.L.F. effects under field conditions.

Materials and Methods:

A. Leaf Preparation and Processing

Fresh tag alder leaves were collected from a grove adjacent to the Ford River near FCD each year. Leaves were removed from whole branches at the laboratory and weighed into individual leafpacks with an average fresh mass of 6.5 gm. Prior to 1988, fresh mass varied between 4.8 and 5.2 gm. After that time, fresh mass was increased to between 6 and 7 gm so that the fresh leafpacks and autumn abscissed leafpacks would have similar numbers of leaves and similar initial dry weights. Each year, care was given in the weighing of replicate leafpacks so that initial fresh weights would be as similar to each other as possible. Because initial dry weights could not be performed on these leaves that were green and fresh when they were put into the stream, low variance in initial fresh weights minimized variability of final dry weights at the sites each collection date. Picked leaves were also gently mixed in their containers prior to construction of the leafpacks in reduce selection bias for any one site.

After leafpacks were weighed, they were taken to the field, lashed to bricks using rubber bands to which replicate identification numbers were attached, and placed in riffles at the FEX and FCD sites. Seven replicates per collection date, per site, and per treatment (fresh versus autumn-abscissed) were used. (In 1984, only five replicates were used.) In the fall of 1990, a new site, called

FEX.LINE was added to the studies for this Element after field testing for ELF intensities showed that the new site experienced higher intensities than did the original FEX experimental site.

In 1984 autumn abscised tag alder were collected in September and used the year of collection. We planned on using leaves reserved from the 1984 leaf collection for 1985 studies; however, we had insufficient numbers and abandoned the autumn leaf study for 1985. Instead, we oven-dried fresh leaves. They proved to be more similar to fresh leaves than to autumn-abscised leaves with respect to their processing rates and so there is a gap in the data for autumn-abscised leaves (1985). In October of 1985 we collected sufficient numbers of leaves for the 1986 study so that we would have autumn abscised leaves available when we collected fresh leaves in 1986. That way, both leaf treatments could be put in the river at the same time. We were no longer constrained by having to wait until fall leaf abscission before initiating the study. Thus, in 1986 and beyond, leaves were placed in the stream earlier in the year than in 1984 and 1985. In 1991, only fresh leaves were used. The autumn-abscised leaves were deleted, with permission, from this element for two related reasons. First, we had a more complete dataset for fresh leaves, and second, reduced allocation of funds for this project will begin in 1992. A similar reduction in work effort is required. By eliminating one treatment, but by adding the new site, FEX.LINE, we feel we can still achieve our goals of complete data analysis.

Leafpacks for both treatments, fresh and autumn-abscised, were collected from the sites six times over a three to four month period. After 1986, it was determined that the critical incubation period was between 21 and 28 days. At those incubation times, the coefficient of variation values for insects colonizing leaves were very low for most of the structural and functional community parameters. We also found that variability for all parameters was very high after 90 days' incubation. As 50% of the dry mass of leaves is usually gone after 54 days, we changed our collection schedule in 1986 to more carefully bracket the critical period between three and four weeks and to delete leaf collection after 90 days. Thus, collection days changed from 3, 9, 24, 50, 90 and 120 days to 7, 14, 21, 28, 50 and 80 days, weather and travel permitting. On collection days, each leafpack was removed carefully from its brick and placed in a plastic box. The portion of the brick touching the leafpack was carefully washed into that box. After returning to the laboratory, each leafpack was washed over a 60 micron mesh sieve, which retained the insects. Insects were preserved in 90% alcohol; leaves were placed in paper triangles and dried at less than 40°C for 48 hr, at which time they were weighed to the nearest 0.01 gm.

Leaf processing rates were computed as $-k/\text{day}$ after Petersen and Cummins (1974). Fresh and autumn-abscised leaf data were analyzed as separate experiments because their physiological differences are considerable. Two-Way ANOVAs were performed on leaf losses after three and one-half to four weeks' incubation to determine any site, year or site-year interaction differences. This incubation period was chosen, as it consistently showed low coefficient of variation values. Processing rates, $-k/\text{day}$ values, were regressed against year, cumulative degree days, and discharge values in a multiple regression analysis for each treatment. B.A.C.I. tests could not be performed on these data sets, as there is only one value mean for each processing rate for each leaf treatment each year. Those tests could not use leaf losses from each collection period either, as leaf losses are related to incubation periods and are fixed to Time 0 when the leaves were put in the stream. Paired t-Tests were used to test for differences in $-k/\text{day}$ values for each treatment over the years.

B. Colonization of Insects on Leaves

The insect taxa from the leaves were determined to the lowest taxon possible. Identified insects were then measured to the nearest mm length for later computation of biomass values (after Smock 1980). Taxon diversity (H'), evenness (J'), richness (S') numbers of individuals, and percent numerical dominance of chironomids, which often comprise over 50% of the total individuals, were computed for each sample. Total insect mass, adjusted for leaf mass values were also computed. An attempt to analyze shredder mass differences failed, owing to very high variance of that functional feeding group among the samples for any particular collection date.

Coefficient of variation (C.V.) values for each estimated parameter from each set of samples were obtained. A power test was used to determine if there were sufficient replicates to be confident 95% of the time that the mean varied no more than $\pm 40\%$ with an alpha of .05. (Seven replicates were sufficient if the parameter had a C.V. value of 20% or less.) If values for any parameter were not normally distributed, they were transformed prior to analysis (e.g., percent data).

The lowest C.V. values for H' , S' , J' , numbers of individuals, percent numerical dominance of chironomids, and total insect biomass adjusted to leaf biomass occurred between 24 and 28 days over the years (See pp. 224, 225,

1988 Annual Report.) Although there are a total of six collection periods, data analyses efforts were concentrated on datasets from that one period in this Annual Report for the reason given above. The variables during that time period were analyzed, using 2-Way ANOVA tests, to determine whether there were site, year, or site x year differences. ANCOVAs for linear data were performed, using cumulative degree days and then cumulative ELF exposure as the covariates.

For three taxa, mean dry biomass per individual (MDW/IND) values were determined for each collection date each year. The three species, Ephemera subvaria, E. invaria, and Isoperla transmarina were then analyzed for differences in growth rates (MDW/IND) between sites and among years. These species are winter and spring growing taxa; quickly changing water temperatures in the fall and spring are related to their growth rates. Physiological time (cumulative degree days) was used as the independent variable in the graphical analyses and chronological time (days in stream) was used as the independent variable in ANCOVA tests to determine whether there were site differences, year by year, for each species.

Results and Discussion

Leaf Processing Rates

1. Fresh Leaves

Processing rates ($-k/\text{day}$) were similar at FEX and FCD except in 1985. 1984 and 1985 are considered pre-operation years. Figure 6.1A shows that in 1985 leaves were processed much faster at FEX than in 1984 and much faster than leaves at FCD in 1985 (Figure 6.1A). Figures for post-operational years show that processing rates were very similar over the years at both sites (Figures 6.2A, B). Processing rates at the new site, FEX.LINE were slower in 1990 than in 1991 (Figure 6.2C). In 1985, a companion experiment to the studies was done 1000 m upstream from the present FEX site. The leaves were placed there as well. Possibly, the site difference for only that year was related to the faster decomposition rates for the fresh leaves there. A student T test showed that there were no statistical differences between the two sites over all years with respect to $-k/\text{day}$ values ($T_{14} = 0.776$, $p = 0.226$).

The yearly variation in $-k/\text{day}$ was almost always higher at FEX than at FCD. The substrate at FEX is more heterogeneous, and many structural and functional community indices are higher at that site. These factors, along with

what appears to be a higher density of omnivorous crayfish (often found in the holes in the brick) at FEX may contribute to the higher variation at FEX.

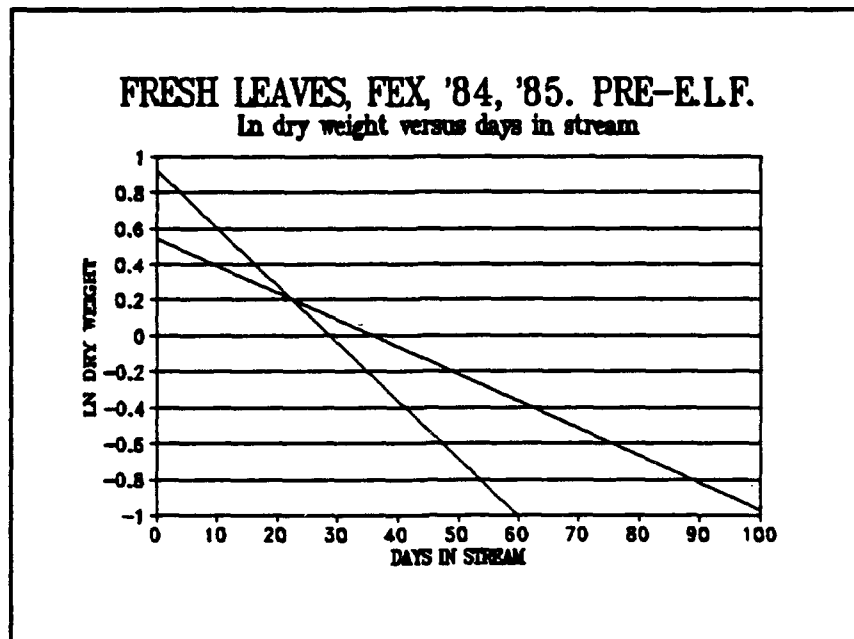


Figure 6.1A. Leaf losses (Ln dry mass) for fresh leaves at FEX, pre-operational. 1984, 1985.

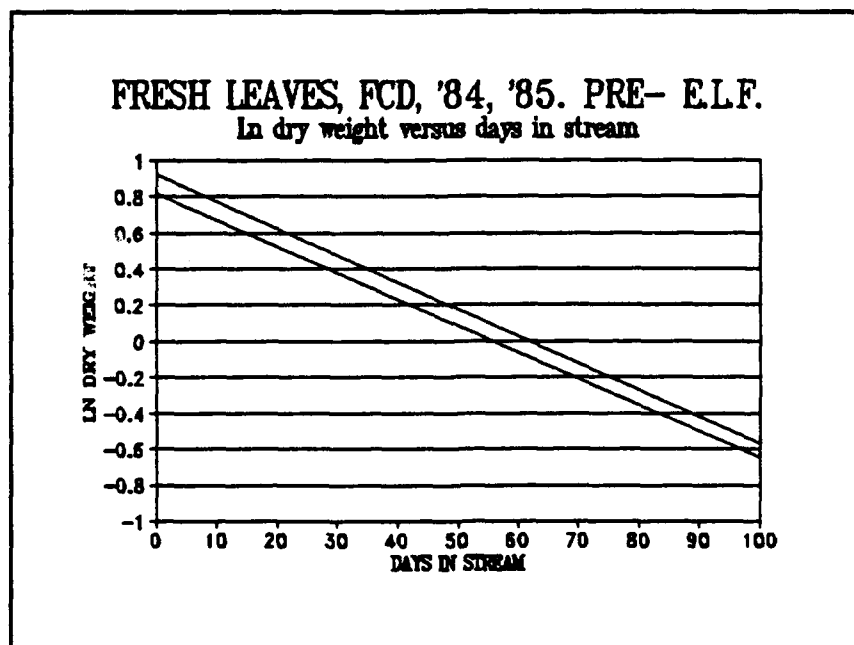


Figure 6.1B. Leaf losses (Ln dry mass) for fresh leaves at FCD, pre-operational. 1984, 1985.

Post-operational processing rates within and between the two sites were very similar, as illustrated in Figures 6.2A and 6.2B.

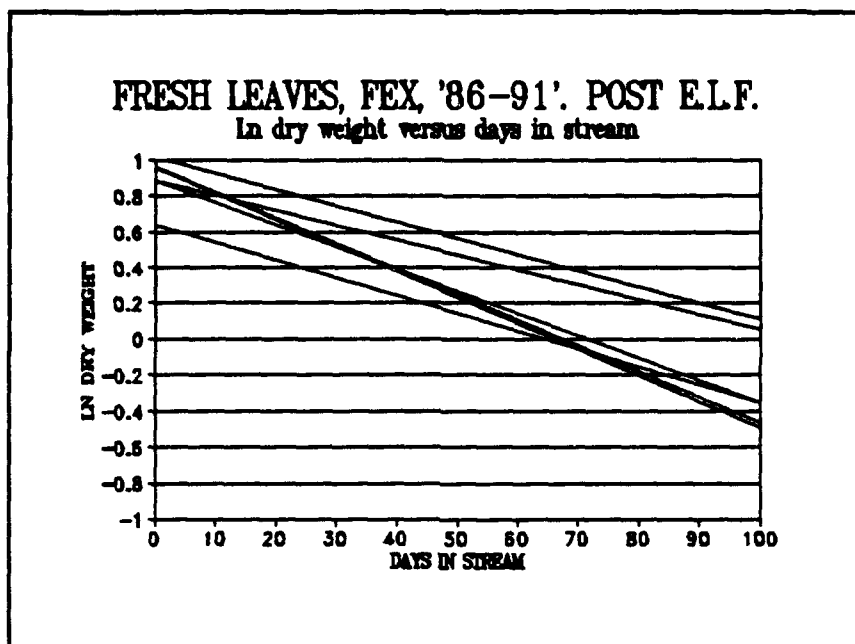


Figure 6.2A. Leaf losses (Ln dry mass) for fresh leaves at FEX, post-operational. 1986 - 1991.

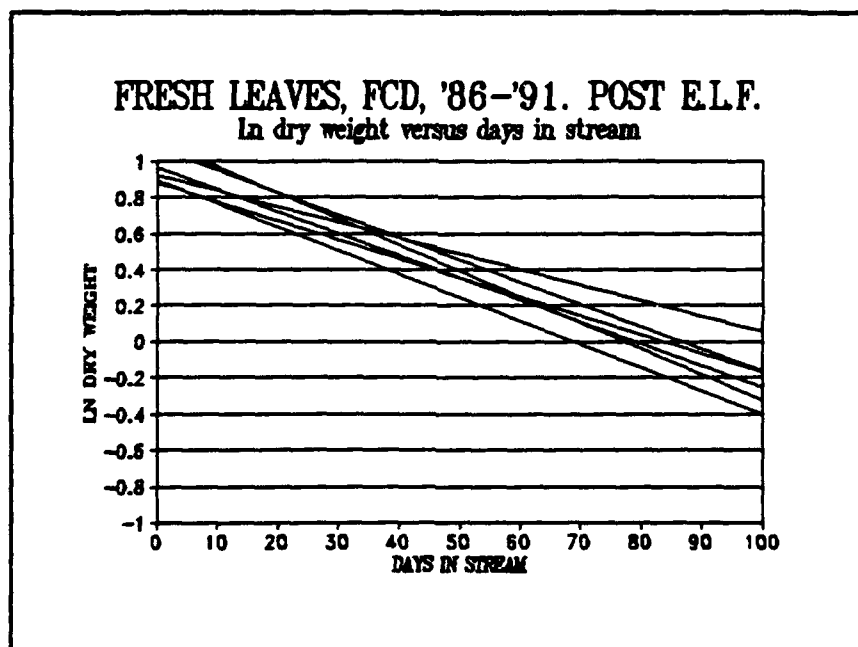


Figure 6.2B. Leaf losses (Ln dry mass) for fresh leaves at FCD, post-operational. 1986 - 1991.

Leaf studies at the new site, FEX.LINE were completed for fresh leaves in 1990 and 1991. Figure 6.2C illustrates those results.

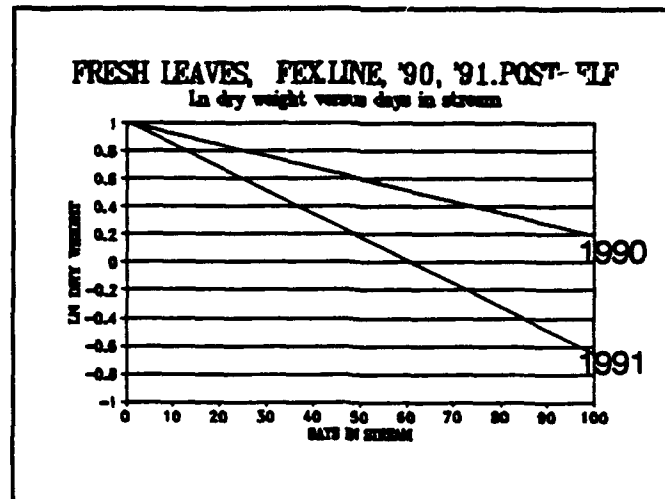


Figure 6.2C. Leaf losses (Ln dry mass) for fresh leaves at FEX.LINE, post-operational. 1990 - 1991.

Table 6.1 presents $-k/\text{day}$ values for fresh leaves at the three sites over time. They are graphically represented in Figure 6.1 and Figure 6.2.

TABLE 6.1
Processing Coefficients ($-k/\text{day}$) and Regression
Coefficients for the slopes of Fresh Leaves
at FEX, FCD, and FEX.LINE, 1984 - 1991

Year	FEX, $-k/\text{day}$	FEX, R ²	FCD, $-k/\text{day}$	FCD, R ²	FEXLINE $-k/\text{day}$	FEXLINE R ²
1984	.0151	.78	.0149	.83		
1985	.0321	.62	1.016	.47		
1986	.0099	.69	.0105	.68		
1987	.0124	.80	.0130	.74		
1988	.0145	.70	.0122	.57		
1989	.0102	.84	.0087	.74		
1990	.0091	.78	.0144	.78	.0081	.62
1991	.0147	.49	.0126	.75	.0166	.68

Over the years, except in 1984 and 1985 at FEX, coefficient of variation values (CV) were low for leaf dry weights after four weeks' incubation in the stream (Figure 6.3). In 1984 and 1985, fresh leaves were put in the stream in late September; in other years, they were put in mid-August or early September. Even so, CV values at the experimental site were consistently higher than at the reference site; this was especially true for 1984 and 1985. Coefficient of variation values tend to go up considerably after 50 percent of the mass of each leafpack is lost. This often occurred for the last two collection dates each year.

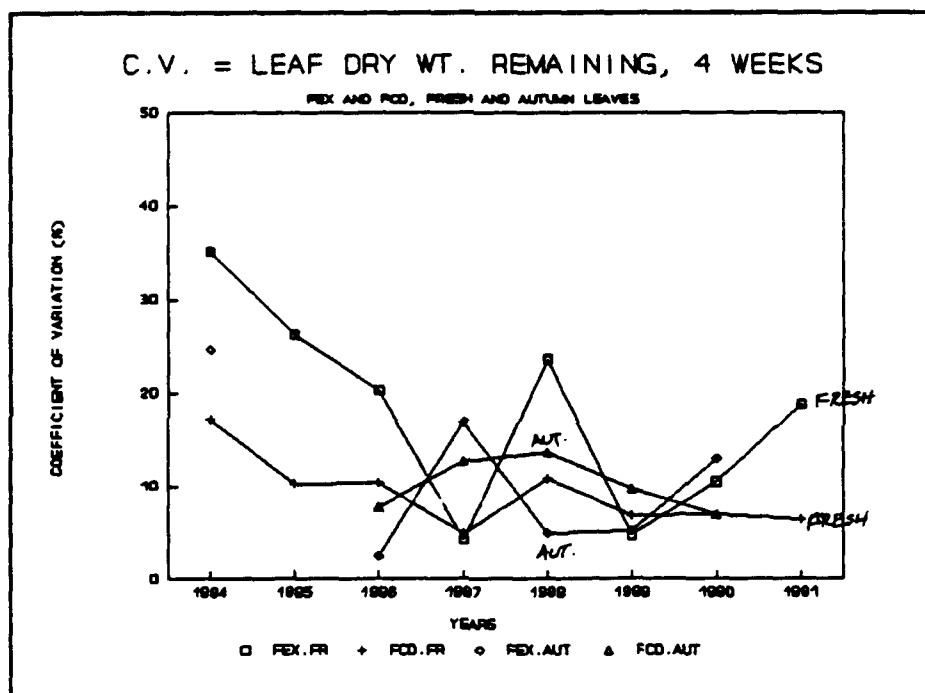


Figure 6.3. Coefficient of variation values for leaf final dry weights after 4 weeks' incubation. FEX fresh (squares), FCD fresh (pluses), FEX autumn (diamonds), and FCD autumn (triangles) leaves, 1984 - 1991.

As will be described later, CV values are at their lowest for insect structural and community parameters at the four week collection period. Therefore, most of our analyses use the four week period data. This is also true for analyses of leaf losses. The lowest C.V. values for leaf loss over the years occurred during the first month the leaves were in the water. Thus, variation in mass remaining values were low for Day 7, 14, 21 and Days 24 through 28, depending on the collection year. A 2-Way ANOVA was performed on leaf dry mass after four weeks' incubation each year (Table 6.2). There were

significant site ($p < .001$), year ($p < .001$) and site by year ($p < .001$) effects for fresh leaves. From 1984 through 1989, initial fresh weights of leaves were increased to try to have the same final dry mass values as for the autumn leaves. The initial fresh weights increased from 4 gm to 7 gm. This change in procedure did not alter rate of change values over the years, but it did alter final dry mass values each year, causing the year effect and the interaction term to be significant over and beyond any real effect. For any given year, however, the treatments were the same at both sites. Site differences would not be attributable to treatment differences. There were, however, significant site differences for this collection date (Table 6.2). In 1984, 1986, and 1987 more leaf material was lost at FEX than at FCD, resulting in the significant site differences for the 24 - 28 day period. When all collection dates were used in the computation of $-k/\text{day}$ values, however, there were no significant differences between sites.

TABLE 6.2
Two-Way ANOVA Tests for Ln Leaf Losses on Fresh Leaves
After 24 to 28 Days at FEX versus FCD, 1984 - 1991

Source	d.f.	SS	MSS	F; Signif.
Years	7	.817	.020	5.23***
Site	1	.700	.017	30.55***
Years, Site	7	.058	.010	9.54***
Error	96	.125	.021	

Differences in water temperatures from year to year can also affect leaf processing and insect community indices. In the pre-operational years of 1983 through 1985, water temperatures over time, as represented by cumulative degree days in Figure 6.4A and B, were cooler than in the post-operational years of 1986 - 89, and 1991.

The cumulative degree day and mean discharge values at the two sites were computed by taking the time from Day 0 when the leaves were put in the stream each year and accumulating, in the case of cumulative degree days, degree day water temperatures until the leaves were collected at the fourth week. The same was true for determining the mean discharge value during that period each year.

Table 6.3 presents values for those physical variables that were used in the multiple regression tests as well as incubation days and deployment date for each year of the study.

TABLE 6.3
Values for Cumulative Degree Days and Discharge Means
at FEX and FCD from 1984 through 1991

Year	Incub.Days	Date In	Cumulative Degree Days		Mean Discharge	
			FEX	FCD	FEX	FCD
1984	24	20 Sept.	187	169	1.27	1.30
1985	24	19 Sept.	172	188	4.85	5.26
1986	27	13 Sept.	261	244	1.93	2.41
1987	26	28 Aug.	354	337	0.50	0.71
1988	28	9 Aug.	480	446	1.03	1.15
1989	27	15 Aug.	464	408	0.70	0.44
1990	27	21 Aug.	399	400	0.44	0.48
1991	27	21 Aug.	433	434	0.59	0.68

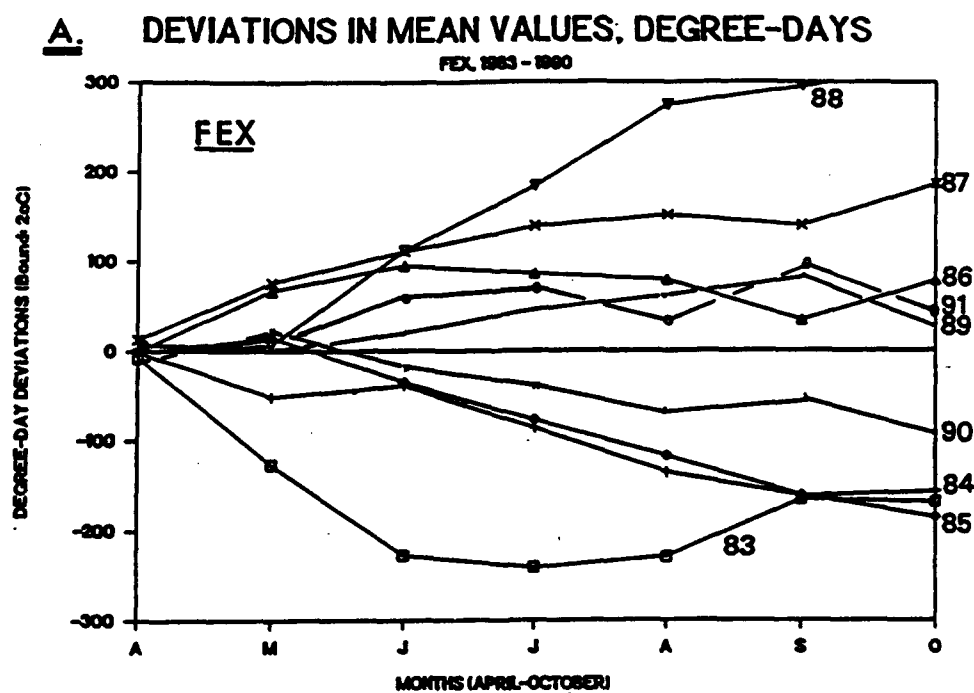


Figure 6.4A. Deviations in mean values for cumulative degree days from 1983 through 1991, FEX.

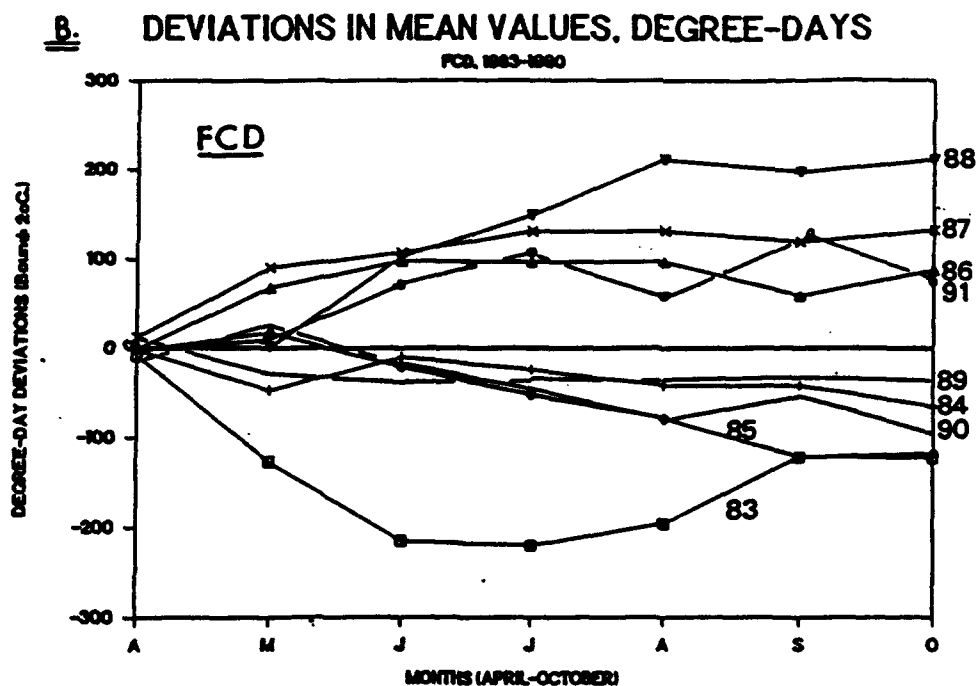


Figure 6.4B. Deviations in mean values for cumulative degree days from 1983 through 1991, FCD.

Extremely dry and warm autumns in 1986, 1987 and 1988 had reduced water flows and temperatures, Figures 4.10, 4.11 in previous Element. These events can have strong impacts on data for our monitoring program. Natural physical phenomena have to be considered when inferences as to possible ELF effects are made. With that in mind, multiple regressions were performed on leaf losses, with physical variables being cumulative degree days and discharge. Table 6.4 gives those results.

TABLE 6.4

Multiple Regression Values for Fresh Leaf Processing Rates
from 1984 through 1991 at FEX and FCD

1. FEX Fresh Leaves

Variable	Reg.Coeff.	Std.Err	T(df=4)	P	Partial
Year	-.00029	.0014	.212	.842	.011
Cum.Deg.Day	.0000008	.00003	-.024	.982	.0001
Discharge	.0048	.0017	2.851	.046	.6702

Std.Err.Est.: .0047 R^2 : .783

Table 6.4, continued

2. FCD Fresh Leaves

Variable	Reg.Coeff.	Std.Err	T(df=3)	P	Partial
Year	.0045	.0032	1.391	.237	.326
Cum.Deg.Day	.00005	.00008	-.645	.554	.094
Discharge	.0002	.0027	.089	.933	.002

Std.Err.Est.: .0087 R²: .475

Table 6.4 shows that the partial regression for discharge at FEX was significant. The partial regression value for years was not very high, suggesting that the variation in fresh leaf losses at or near FEX were related more to variation in discharge than to before versus after effects of ELF. At the reference site, FCD, no variables including discharge, were strongly correlated with leaf losses and the regression coefficient was below 0.50. Other independent variables may be more important at the reference site; for example, insect feeding activity.

2. Autumn-Abscised Leaves

As described in the Materials and Methods section, autumn-abscised leaf studies were deleted from this Element after 1990. Autumn-abscised leaves were processed somewhat faster at FEX than at FCD (Figure 6.5A, 6.5B, Table 6.5). However, there were no significant site differences for autumn leaf $-k/day$ values over the years ($T = .871$, $df = 10$, $p = 0.202$). In 1990, autumn leaf processing rates were faster than in previous years (figures and table above); yet the same differences between FEX and FCD held; autumn leaves were processed faster at FEX than at FCD. Rates at the new site, FEX.LINE, were slower than at FEX or FCD, Figure 6.5C (See also Table 6.5).

The variance from year to year for processing rates, which is the slope of the line for 42 values taken over six time periods, at both sites has been relatively high (C.V. at FEX = 42.17%; C.V. at FCD = 52.81%). Was the variation from year to year owing to ELF effects or to some physical factor(s) that affected processing rates? Multiple linear regression tests on data for leaves incubated in the stream for four weeks were performed to see whether differential physical factors relating to time of year and to yearly differences were associated with different processing coefficients, $-k/day$, Table 6.6.

AUTUMN LEAVES, FEX: 1984, 1986 - 1990
Ln dry weight versus days in stream

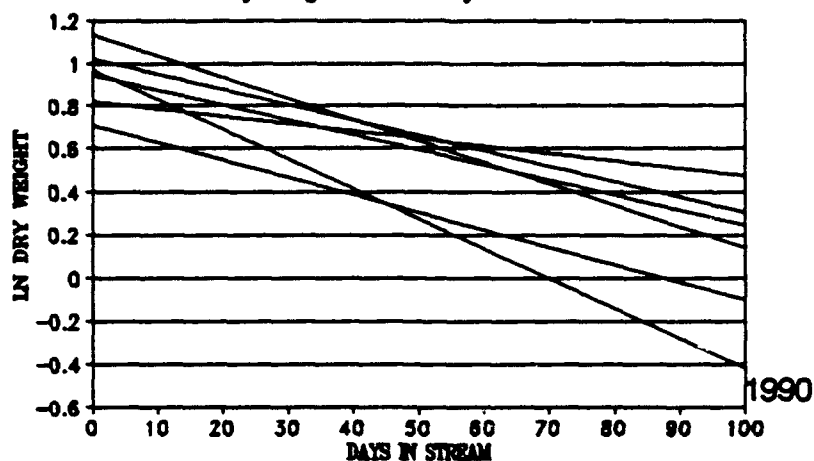


Figure 6.5A. Leaf losses (Ln dry mass) for autumn leaves at FEX. 1984; 1986 - 1990.

AUTUMN LEAVES, FCD: 1984, 1986 - 1990
Ln dry weight versus days in stream

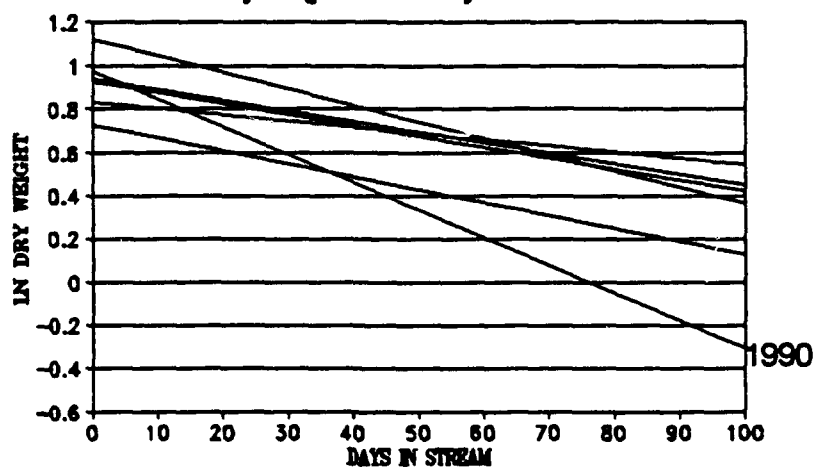


Figure 6.5B. Leaf losses (Ln dry mass) for autumn leaves at FCD. 1984; 1986 - 1990.

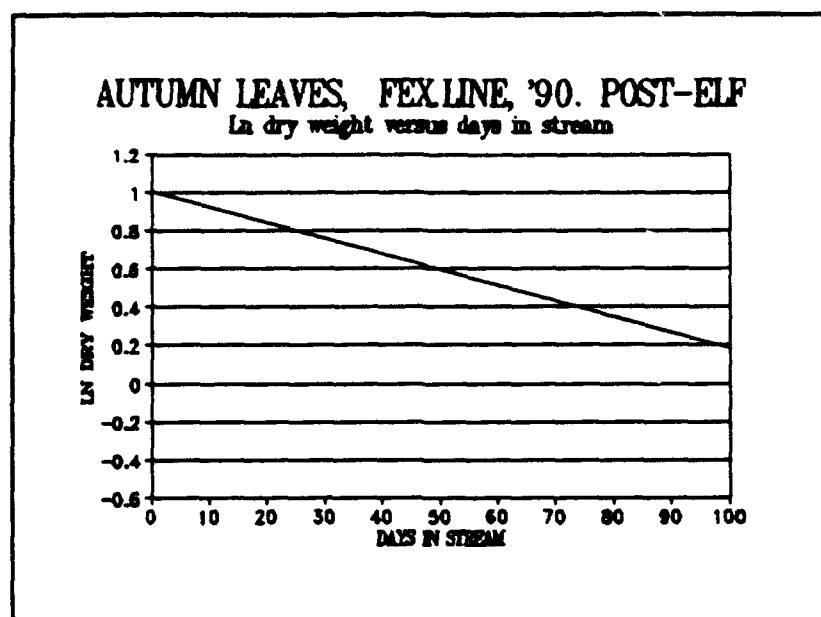


Figure 6.5C. Leaf losses (Ln dry mass) for autumn leaves at FEX.LINE, 1990.

Table 6.5 shows that, in general, autumn leaves were processed faster at FEX than at FCD and that R^2 values were higher for that site as well. Even so, there were no significant differences between the sites over the years.

TABLE 6.5
Processing Coefficients ($-k/\text{day}$) and Regression
Coefficients for the slopes of Autumn Leaves
at FEX, FCD, and FEX.LINE, 1984 - 1990

Year	FEX, $-k/\text{day}$	FEX, R^2	FCD, $-k/\text{day}$	FCD, R^2	FEXLINE $-k/\text{day}$	FEXLINE R^2
1984	.0081	.67	.0060	.50		
1986	.0035	.86	.0029	.36		
1987	.0070	.52	.0050	.27		
1988	.0072	.83	.0049	.42		
1989	.0099	.77	.0076	.60		
1990	.0138	.56	.0128	.72	.0082	.65

Multiple regression tests were performed to see whether differential physical factors relating to time of year and to yearly differences were associated with differential leaf losses, Table 6.6. No independent variable was significantly associated with autumn leaf processing rates.

TABLE 6.6
Multiple Regression Values for Autumn Leaf Processing Rates
1984; 1986-1990 at FEX and FCD

1. FEX Autumn Leaves

Variable	Reg.Coeff.	Std.Err	T(df=2)	P	Partial
Year	-.0013	.0011	-1.167	.364	.405
Cum.Deg.Day	.00002	.00002	1.034	.410	.348
Discharge	.0038	.0028	1.361	.306	.481

Std.Err.Est.: .0027 R²: .762

2. FCD Autumn Leaves

Variable	Reg.Coeff.	Std.Err	T(df=3)	P	Partial
Year	-.0021	.0011	-1.999	.184	.666
Cum.Deg.Day	.00004	.00002	1.751	.222	.605
Discharge	.0025	.0017	1.443	.286	.512

Std.Err.Est.: .0022 R²: .833

Figure 6.3 shows that coefficient of variation values over the years for autumn leaves after they had been in the stream four weeks each year were below 18%, except for 1984. Two-Way ANOVA tests for leaf loss after 24 - 28 days were run to see whether there were site or year differences for autumn leaf losses in that collection period each year (Table 6.7). Although there were no significant year differences and the interaction term was not significant, there were significant site differences. Leaf losses were high at FEX in 1984 and in 1990. One of those years was pre-operational and one was post-operational. It appears that ELF activation was not associated with these site differences for autumn leaf loss after 24 to 28 days at the two sites.

TABLE 6.7
Two-Way ANOVA Tests for Ln Leaf Losses on Autumn Leaves
After 24 to 28 Days, FEX versus FCD, 1984; 1986-1990

Source	d.f.	SS	MSS	F; Signif.
Years	5	1.232	.246	0.663
Site	1	0.010	.010	13.613***
Years, Site	5	0.060	.012	0.552
Error	72	1.303	.018	

Figure 6.6 is a plot of the difference values (FEX minus FCD) for fresh and for autumn-abscised leaf processing rates over the years of the study. The greatest differences occurred in 1985 and 1990 for fresh leaves and 1990 for autumn leaves.

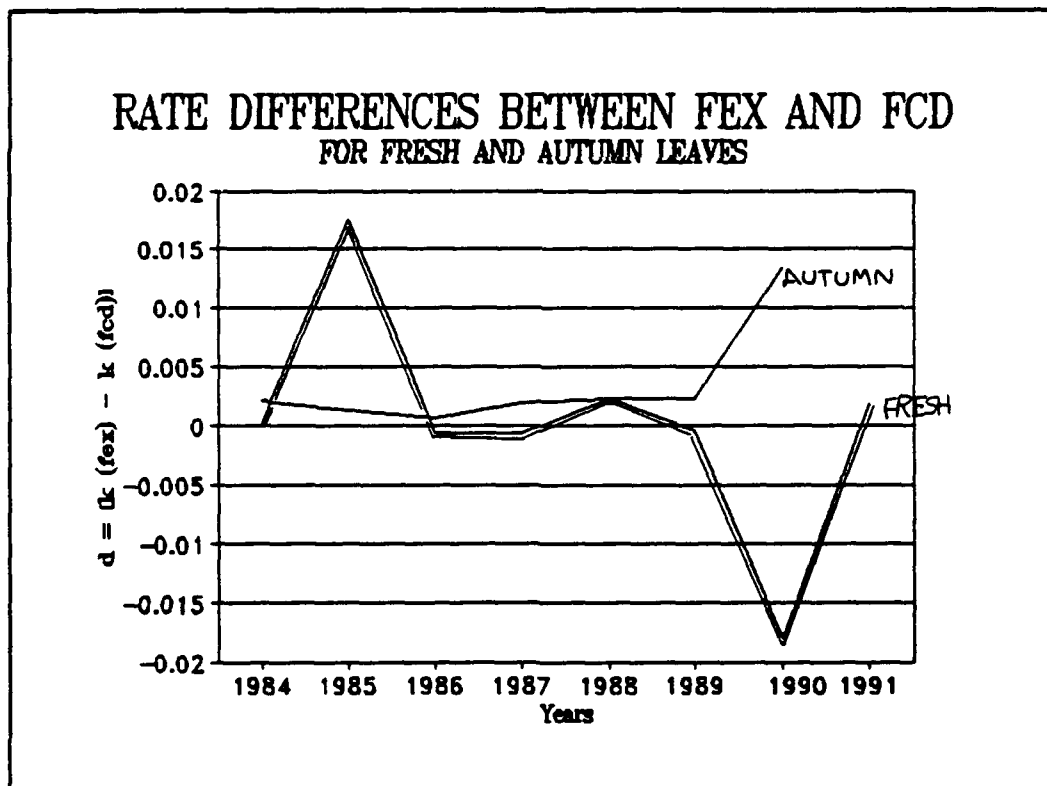


Figure 6.6. Leaf processing rate differences between FEX and FCD for Fresh (A) and Autumn-abscised (B) leaves from 1984 through 1991. (No data are available for autumn leaves in 1985. A continuous line is drawn for heuristic purposes.)

The fast processing coefficient for fresh leaves at FEX in 1985 has been already described. Leaf processing rate differences for both fresh and autumn leaves deviated in 1990. However, in 1991 differences for fresh leaves were small and were similar to differences seen in 1984 and in 1986 through 1989. Although autumn leaves were always processed faster at FEX than at FCD, a high $-k/day$ value at FEX in 1990 increased the difference between the two sites for this coefficient. Fresh leaves were processed very slowly at FEX relative to FCD, dramatically shifting the difference values well below the 0 difference line. Reasons for these altered patterns in 1990 are unknown. The collection protocol, leafpack preparation, and location of leafpacks in the river were similar to prior years. In 1990 autumn leaves were processed faster than fresh leaves at FEX. This has never happened before. Although autumn leaves were processed faster at FCD than ever before, fresh leaves were processed at a rate within the range of prior years. E.L.F. was fully operational in 1990. If E.L.F. affects leaf processing rates, the responses by autumn leaves differ from the responses of fresh leaves.

Insects Colonizing Leafpacks

Structural Community Parameters:

We have shown that the lowest mean to variance ratios (C.V. values) for structural community parameters occurred when leaves had been in the river approximately four weeks. We used data for that time period to look for any differences between the two sites across years. We have also shown that the aquatic insects appear to prefer fresh over autumn leaves (Stout and Taft, 1985). Fresh leaf and autumn leaf experiments are handled separately in the statistical analyses, but both treatments are presented together in the figures for illustrative purposes. Graphs of mean values and of CV values for the structural community parameters from replicates taken after four weeks' incubation each year are presented first; then statistical analyses follow.

Taxon diversity (H') was higher on autumn leaves than on fresh leaves, except in 1984 (Figure 6.7A). There was an overall decrease in diversity over the years, with the exception that in 1989 H' rose at the two sites. Communities were more diverse at FEX than at FCD for each treatment. Coefficient of variation values were high for fresh leaves at FEX in 1985; otherwise, they were less than 20 percent (Figure 6.7B). In 1985, leaves were placed upstream approximately 1000 m from the usual FEX site. It is probable that the high CV value only then was associated with the location of the samples.

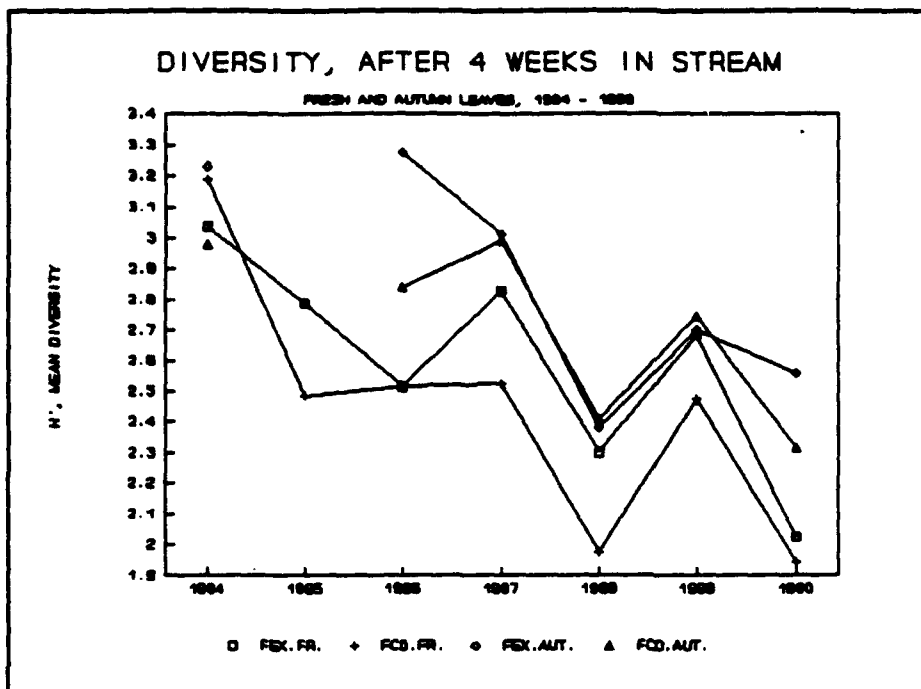


Figure 6.7A. Mean taxon diversity on fresh and autumn leaves, 1984 - 1990. Squares: FEX Fresh (squares), FCD Fresh (pluses), FEX Autumn (diamonds), FCD Autumn (triangles).

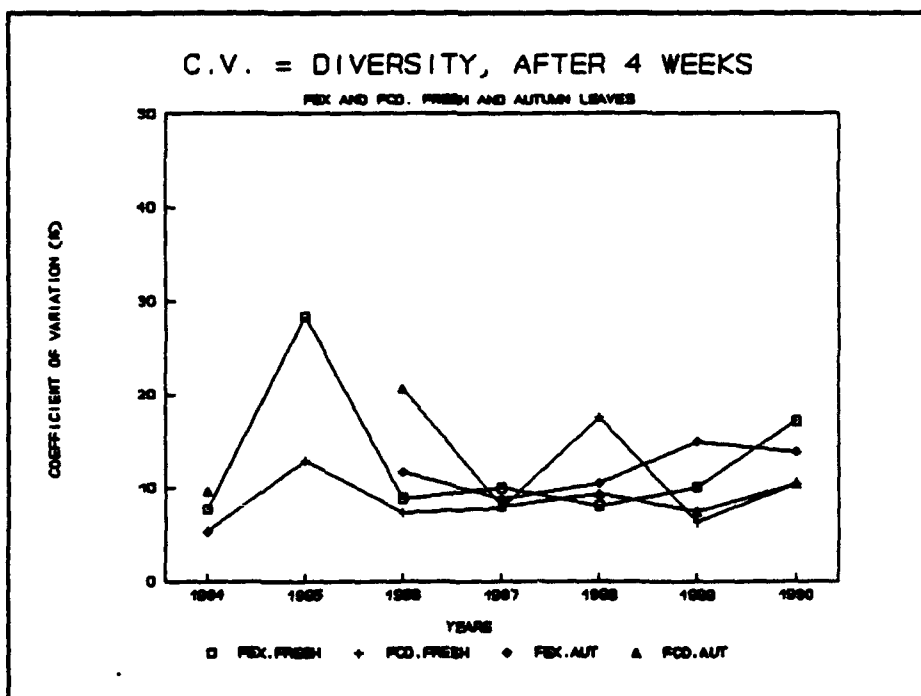


Figure 6.7B. Coefficient of Variation values for taxon diversity, 1984 - 1990. FEX Fresh (squares), FCD Fresh (pluses), FEX Autumn (diamonds), FCD Autumn (triangles).

A Two Way ANOVA for fresh or autumn leaves showed no significant interaction between years and sites, but it did show significant year and significant site effects (Table 6.8). Almost without exception, taxon diversity was higher at FEX, irrespective of treatment (Figure 6.7A). Additionally, H' declined over the years, except in 1989. Table 6.3 shows that we collected samples for Week Four earlier in the season over the years. Graphs to be presented later will show that numbers of individuals and chironomid dominance increased over the years, while taxon diversity and taxon evenness decreased. These differences may be owing more to collection date differences than to differences, year by year.

TABLE 6.8
Two-Way ANOVA Tests for H' for Insects on (A) Fresh and for
(B) Autumn Abscised Leaves After 24 to 28 Days, 1984 - 1990

Source	d.f.	SS	MSS	F value
(A) FRESH				
Years	6	11.556	1.926	38.831***
Site	1	0.621	0.621	12.510***
Interaction	6	0.656	0.109	2.205
Error	84	4.624	0.050	
(B) AUTUMN				
Years	5	6.971	1.394	19.151***
Site	1	0.594	0.594	8.159*
Interaction	5	0.522	0.104	1.435
Error	72	6.670	0.073	

B.A.C.I. tests cannot be run on these data to see whether there is a before versus after effect because there is only one mean value per year. B.A.C.I. tests are not very powerful; moreover, they do not incorporate variation in the data. Variation may be more important than mean values for these studies. For example, ELF exposure may have some threshold effect that increases variance around a similar mean value. ANCOVAS were run to relate site and year differences in diversity to natural, physical differences and/or to ELF effects, using cumulative degree days and then ELF cumulative exposure as the covariates (Table 6.9). There is one major problem in using ELF cumulative exposure as a covariate for our data. ELF exposure values were not taken independently at FCD. They were derived from taking one or two measurements each year at FCD and then 'filling in' the data by extrapolating from ELF ground field exposure values. Therefore, my intent in performing these ANCOVAS was to see whether there were differences in slopes (a differential response to ELF fields) rather than to see whether there were differences in intercept mean values.

TABLE 6.9
ANCOVAS for H'; (A) Cumulative Degree Days, 1984-1990
(B) Cumulative ELF Exposure, 1986-1990

<i>FRESH</i>	<i>F values Adj.Means</i>	<i>F values Slopes</i>	<i>AUTUMN</i>	<i>F values Adj.Means</i>	<i>F values Slopes</i>
<i>A. Cum. Degree Day</i>	8.528**	3.189	<i>A. Cum. Deg.Day</i>	6.887*	1.022
<i>d.f.</i>	1,89	1,88	<i>d.f.</i>	1,74	1,73
<i>B. ELF Exposure</i>	14.749***	0.225	<i>B. ELF Exposure</i>	14.681***	0.036
<i>d.f.</i>	1,65	1,64	<i>d.f.</i>	1,64	1,63

There were significant differences in adjusted mean values for H' on fresh and autumn leaves for both covariates; but there were no differences in slopes. The differences in adjusted mean values may be owing to the continual differences in diversity at the two sites rather than to the physical natural and anthropogenic factors. Multiple regressions will be run for the Revised Annual Report to determine if other physical factors are more important than the ones presented.

Taxon evenness (Figure 6.8A, Figure 6.8B) had patterns similar to those for taxon diversity (Figure 6.7A, Figure 6.7B).

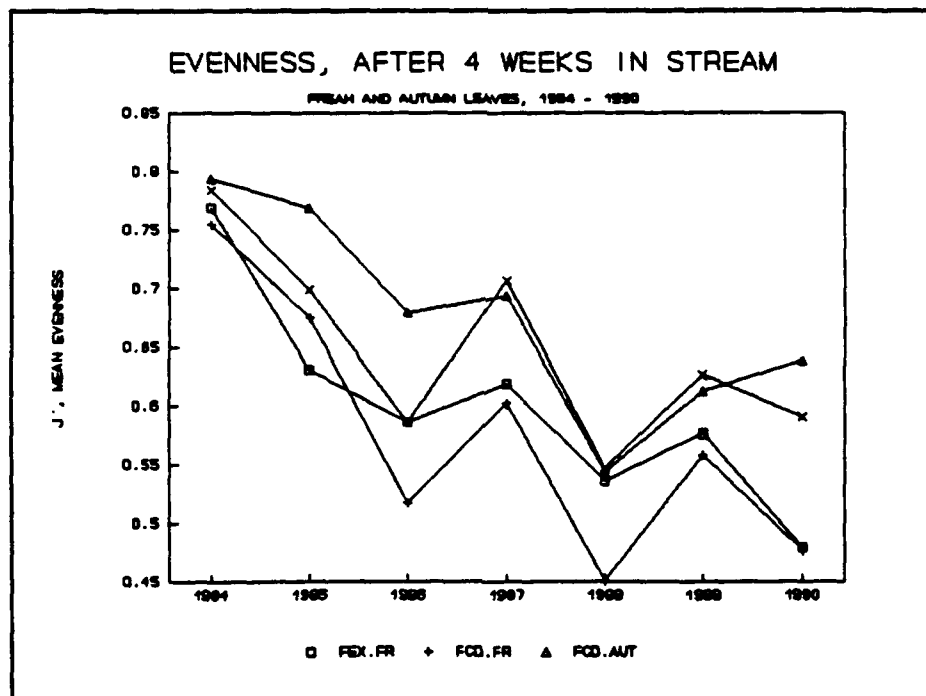


Figure 6.8A. Taxon Evenness (J') on Fresh and Autumn Leaves at FEX and FCD. 1984 - 1990. FEX Fresh (squares), FCD Fresh (pluses), FEX Autumn (diamonds), FCD Autumn (triangles).

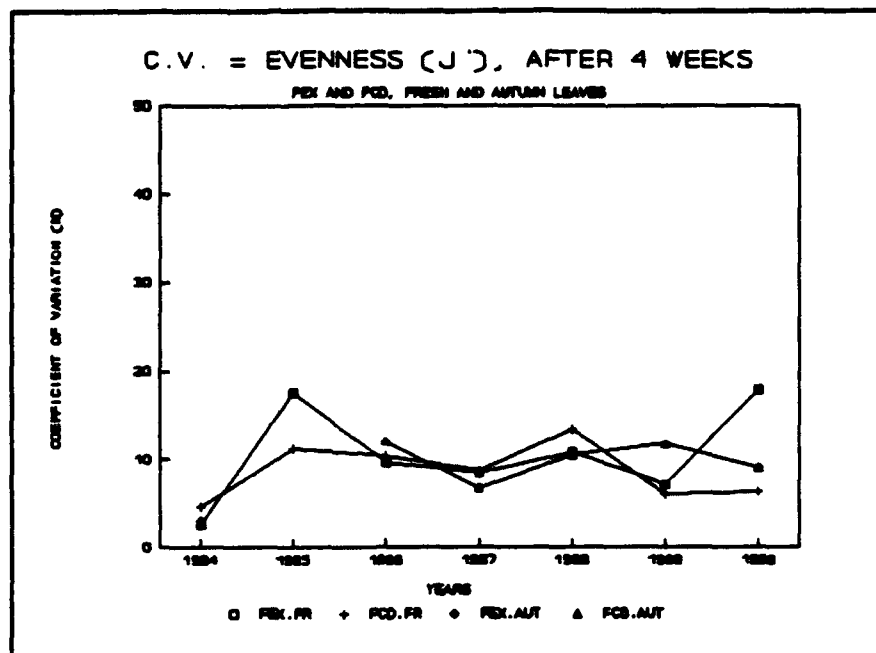


Figure 6.8B. Coefficient of Variation values for Taxon Evenness at FEX and FCD. 1984 - 1990. FEX Fresh (squares), FCD Fresh (pluses), FEX Autumn (diamonds), FCD Autumn (triangles).

Table 6.10 presents a Two-Way ANOVA table testing for differences between the sites and years for taxon evenness.

TABLE 6.10
Two-Way ANOVA Tests for J'(Arc Sine Transform) for Insects on (A) Fresh and (B) Autumn Abscised Leaves After 24 to 28 Days, 1984 - 1990

Source	d.f.	SS	MSS	F value
(A) FRESH				
Years	6	2854.58	475.76	45.64***
Site	1	22.26	22.26	2.135
Interaction	6	95.05	15.84	1.520
Error	84	984.00	10.42	
(B) AUTUMN				
Years	5	1956.00	391.20	50.172***
Site	1	34.10	34.10	4.374*
Interaction	5	120.59	24.12	3.093*
Error	72	802.43	7.80	

Fresh leaves showed significant year differences and autumn leaves showed significance for both main effects and the interaction term. Figure 6.8A shows that evenness declined over the years for both treatments at both sites; again, as for H', evenness increased in 1989. Table 6.11 shows results from ANCOVA tests, with cumulative degree days (A) and ELF cumulative ground exposure (B) being the covariates for each of the tests.

TABLE 6.11
ANCOVAS for J' (A) Cumulative Degree Days, 1986-1990
(B) Cumulative ELF Exposure, 1986-1990

FRESH	F values Adj.Means	F values Slopes	AUTUMN	F values Adj.Means	F values Slopes
A. Cum. Degree Day	5.000*	1.256	A. Cum. Deg.Day	3.047 n.s.	2.534
d.f.	1,62	1,61	d.f.	1,64	1,63
B. ELF Exposure	13.751***	0.000	B. ELF Exposure	5.390*	0.317
d.f.	1,62	1,61	d.f.	1,64	1,63

Adjusted mean values for y-intercepts were significant in all except one case (J' for autumn leaves vs. cumulative degree days). As the slopes did not differ, no ELF effect can be detected; however, the ELF exposure data for this test lacks independent measurement at both sites, as described earlier. Thus any statistical tests using these data should not have assumptions requiring independent measurements of this variable.

Taxon richness did not show a steady decline over the years (Figure 6.9B). In fact, richness on fresh leaves at the two sites did not track each other very well until 1988. Taxon richness on autumn leaves was low in 1985; high in 1986, and then moderate in the following years. The two sites were similar over the years for taxon richness. Coefficient of variation values were high at FEX in 1985, for reasons described earlier (Figure 6.9B). They were also high for fresh leaves at FCD. No reasons for this are apparent at this time. From 1987 through 1990, CV values were below 20 percent.

Although 2-Way ANOVAS were performed for taxon richness, ANCOVAS could not be run, as the data are not linear. Table 6.12 shows that there was a significant year effect and significant interaction between years and site for fresh leaves. Figure 6.9A shows that FEX and FCD alternated in having the highest numbers of taxa each year of the study. Taxon richness on autumn leaves showed a significant year and site effect, but there was no significant interaction between the main factors. Figure 6.9A shows that FEX autumn leaves usually

had higher taxon richness. In 1986, numbers of taxa were very high at both sites; whereas, they were very low in 1984.

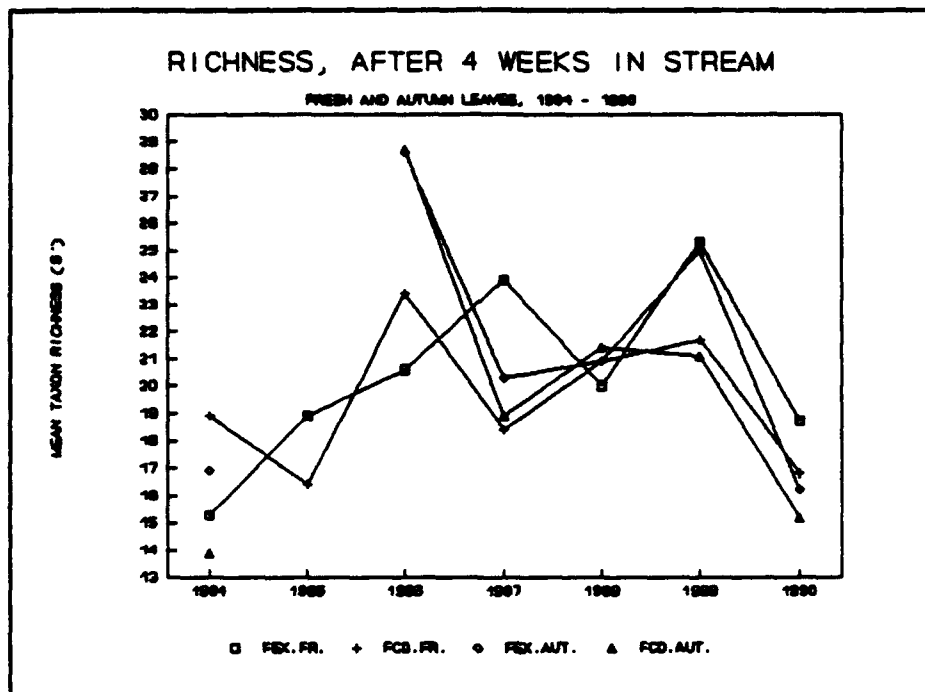


Figure 6.9A. Mean Taxon Richness (S) on Fresh and Autumn Leaves at FEX and FCD, 1984 - 1990. FEX Fresh (squares), FCD Fresh (pluses), FEX Autumn (diamonds), FCD Autumn (triangles).

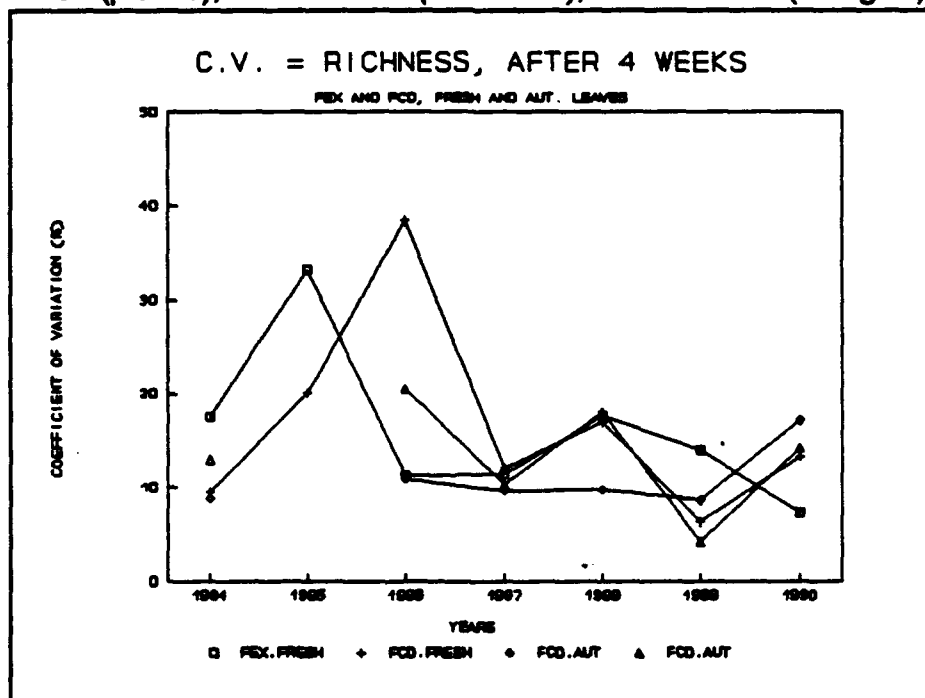


Figure 6.9B. Coefficient of Variation values for taxon richness (S) at FEX and FCD. 1984 - 1990. FEX Fresh (squares), FCD Fresh (pluses), FEX Autumn (diamonds), FCD Autumn (triangles).

TABLE 6.12
Two-Way ANOVA Tests, Taxon Richness for Insects on (A) Fresh and for
(B) Autumn Abscised Leaves After 24 to 28 Days, 1984 - 1990

Source	d.f.	SS	MSS	F value
(A) FRESH				
Years	6	514.490	85.748	15.317***
Site	1	18.00	18.000	3.215
Interaction	6	238.286	39.714	7.094***
Error	84	510.857	5.598	
(B) AUTUMN				
Years	5	1738.857	347.771	40.394***
Site	1	42.857	42.857	4.978*
Interaction	5	52.571	10.514	1.221
Error	72	538.286	8.610	

Numbers of individuals on the leaves generally increased through time, except for 1988 and 1990 (Figure 6.10A). Numbers were higher on fresh leaves at FEX some years and were higher on fresh leaves at FCD other years. However, numbers tracked one another more closely for autumn leaves even though the highest numbers oscillated between FEX and FCD over the years. Coefficient of variation values were highest for fresh leaves in 1985 (at the site upstream of FEX used that year) at FEX; CV values oscillated much more for fresh leaves at FEX than for any other treatment and/or site (Figure 6.10B).

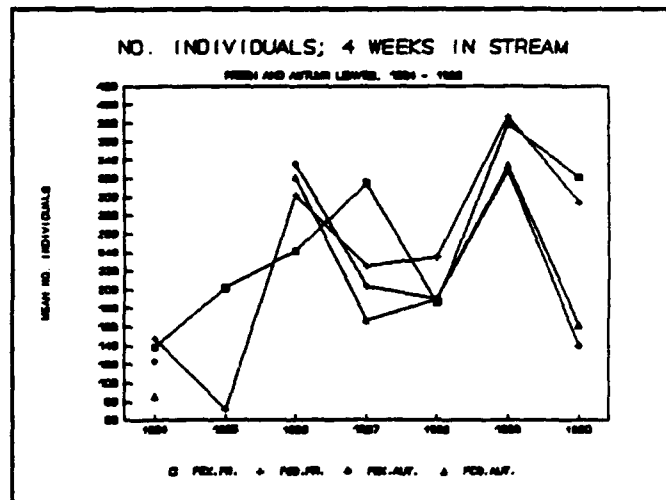


Figure 6.10A. Mean number of individuals on Fresh and Autumn leaves at FEX and FCD. 1984 - 1990. FEX Fresh (squares), FCD Fresh (pluses), FEX Autumn (diamonds), FCD Autumn (triangles).

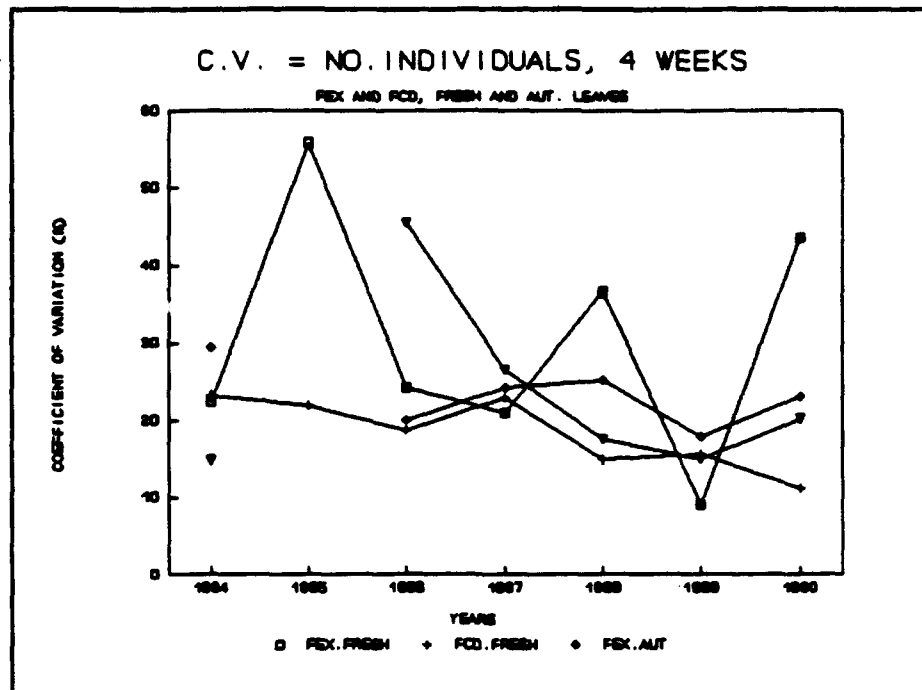


Figure 6.10B. Coefficient of Variation values for Number of Individuals at FEX and FCD. FEX Fresh (squares), FCD Fresh (pluses), FEX Autumn (diamonds), FCD Autumn (triangles).

Table 6.13 presents results for a 2-Way ANOVA for numbers of individuals on fresh and autumn leaves over the years.

TABLE 6.13
Two-Way ANOVA Tests, Numbers of Insects on (A) Fresh and for
(B) Autumn Abscised Leaves After 24 to 28 Days, 1984 - 1990

Source	d.f.	SS	MSS	F value
(A) FRESH				
Years	6	1445836	240973	3.209*
Site	1	128380	128380	1.709
Interaction	6	577248	96208	1.281
Error	84	6359564	75103	
(B) AUTUMN				
Years	5	1612346	122469	76.802***
Site	1	1196	1196	0.750
Interaction	5	7973	1595	0.475
Error	72	243640	3356	

Numbers of individuals showed significant year differences between the two sites. Figure 6.10A shows that numbers of individuals, except in 1988, gradually increased over the years on fresh leaves. 1988 was the warmest summer and fall over the period of our study. Warmer water temperatures and low rainfall may account for the lower insect abundances at FEX where deployment of leaves was in shallower waters than at FCD. There were two peaks in 1986 and in 1989. Because numbers of individuals on fresh and autumn leaves do not increase or decrease linearly with time, ANCOVAS were not performed.

Many chironomids colonize leaf inputs in the Ford River, and our introduced leafpacks are no exception. They dominate many of our samples. Because they are very common, include several functional feeding groups, and show patterns of dominance over the 'life' of each leafpack season as well as among the years of our leafpack studies, we analyzed their dominance for this Report. Figure 6.11A shows mean dominance and Figure 6.11B, CV values for that family.

Chironomid dominance increased over the years for samples taken after four weeks' incubation each year. Except in 1984 and 1985, chironomids dominated the fresh leafpack samples at FCD more than at FEX. This was not true for chironomids on autumn leaf packs. Some years, dominance was higher at FEX and other years it was higher at FCD (Figure 6.11A). Figure 6.11B shows that CV values for dominance on autumn leaves decreased over time. On fresh leaves, CV values peaked in 1985, but decreased to less than 20 percent after 1986. Table 6.14 shows the relationships between years and sites for this biotic parameter.

TABLE 6.14
Two-Way ANOVA Tests, Chironomid Numerical Dominance on (A) Fresh and for
(B) Autumn Abscised Leaves After 24 to 28 Days, 1984 - 1990

<i>Source</i>	<i>d.f.</i>	<i>SS</i>	<i>MSS</i>	<i>F value</i>
(A) FRESH				
<i>Years</i>	6	3034.742	505.790	14.219***
<i>Site</i>	1	8.264	8.264	0.232
<i>Interaction</i>	6	458.102	76.350	2.146
<i>Error</i>	84	2325.282	35.572	
(B) AUTUMN				
<i>Years</i>	5	3320.247	664.049	32.484***
<i>Site</i>	1	20.016	20.0163	0.979
<i>Interaction</i>	5	481.827	96.365	4.714**
<i>Error</i>	72	1414.294	20.442	

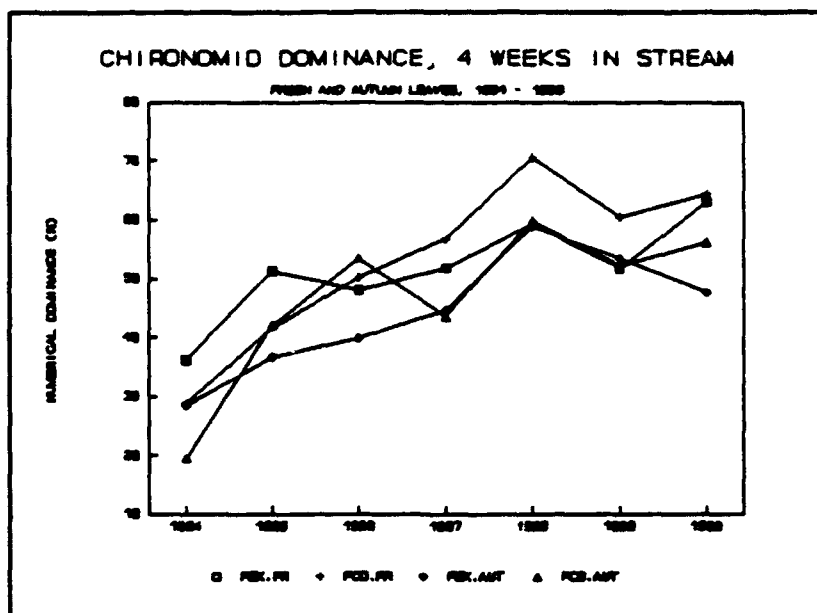


Figure 6.11A. Mean chironomid dominance on Fresh and Autumn leaves at FEX and FCD, 1984 - 1990. FEX Fresh (squares), FCD Fresh (pluses), FEX Autumn (diamonds), FCD Autumn (triangles).

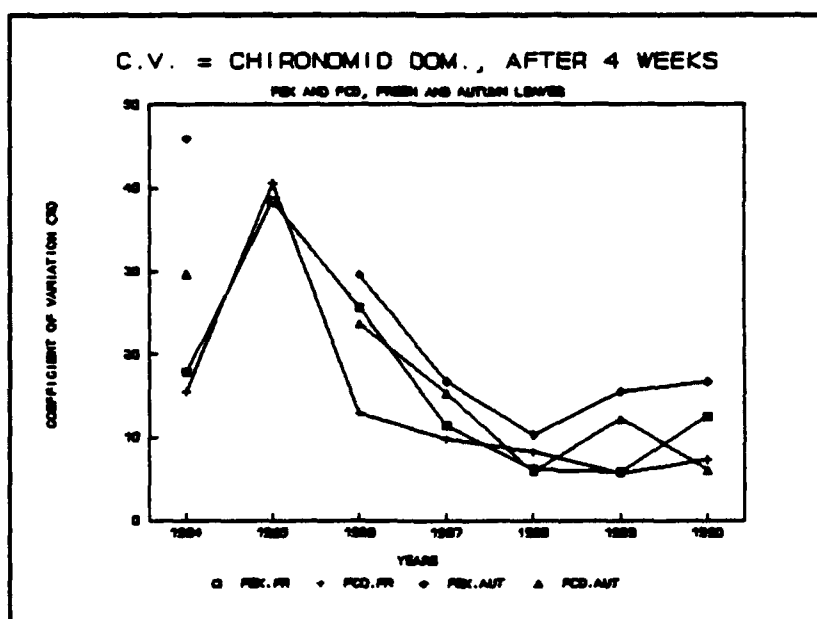


Figure 6.11B. Coefficient of Variation values for Chironomid Dominance at FEX and FCD, 1984 1990. FEX Fresh (squares), FCD Fresh (pluses), FEX Autumn (diamonds), FCD Autumn (triangles).

Chironomid dominance on fresh leaves showed significant year differences. Dominance continued to increase over the years (Figure 6.11A). The significant interaction term for dominance on autumn leaves was owing to an inconsistent pattern of dominance at the two sites. Because dominance for both treatments was linear over time, ANCOVAS were performed, Table 6.15. Each of the covariates showed that there were adjusted mean differences for the two leaf treatments. There were no slope differences for fresh leaves. There were slope differences for autumn leaves when cumulative degree days were used as the covariate.

TABLE 6.15
ANCOVAS for Chironomid Dominance. (A) Cumulative Degree Days, 1986-1990
(B) Cumulative ELF Exposure, 1986-1990

FRESH	<i>F values Adj.Means</i>	<i>F values Slopes</i>	AUTUMN	<i>F values Adj.Means</i>	<i>F values Slopes</i>
A. Cum. Degree Day	5.759*	3.748	A. Cum. Deg.Day	15.484***.	5.088*
d.f.	1,64	1,63	d.f.	1,62	1,61
B. ELF Exposure	8.956**	0.389	B. ELF Exposure	24.858***	0.397
d.f.	1,64	1,63	d.f.	1,62	1,61

Functional Community Parameters

1. Total Insect Mass

Figure 6.12A shows the mean values for total insect mass after 24 - 28 days' incubation over the years. They were similar over time until 1989 when means were very high. In 1990 total mass/leaf mass dropped from 1989 levels for both treatments at FEX except for adjusted insect mass on fresh leaves at FCD.

Coefficient of variation values were very high for this parameter (Figure 6.12B). There was no year where all of the values were less than 50 percent. The probability of detecting any ELF, or for that matter, any natural physical effect on the means of this parameter are very small indeed. Thus, only 2-Way ANOVAS were run for this parameter. Table 6.16 shows that there were significant year differences between the two sites for both fresh and autumn leaves. Autumn leaves showed significant site effects and the interaction term was significant as well. Total insect mass/leaf mass on autumn leaves was the only parameter and treatment for which all terms in the 2-Way ANOVA were significant. Figure 6.12B depicts the 'worst' coefficient of variation plot we had for the six biotic parameters.

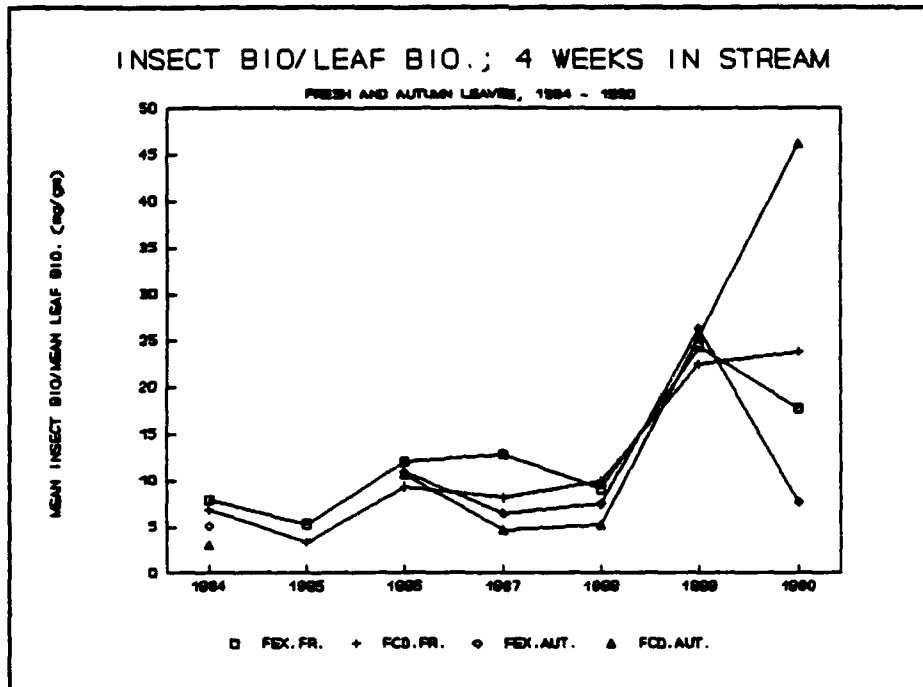


Figure 6.12A. Mean Total Mass/Leaf Mass (mg./gm) at FEX and FCD, 1984 - 1990. FEX Fresh (squares), FCD Fresh (pluses), FEX Autumn (diamonds), FCD Autumn (triangles).

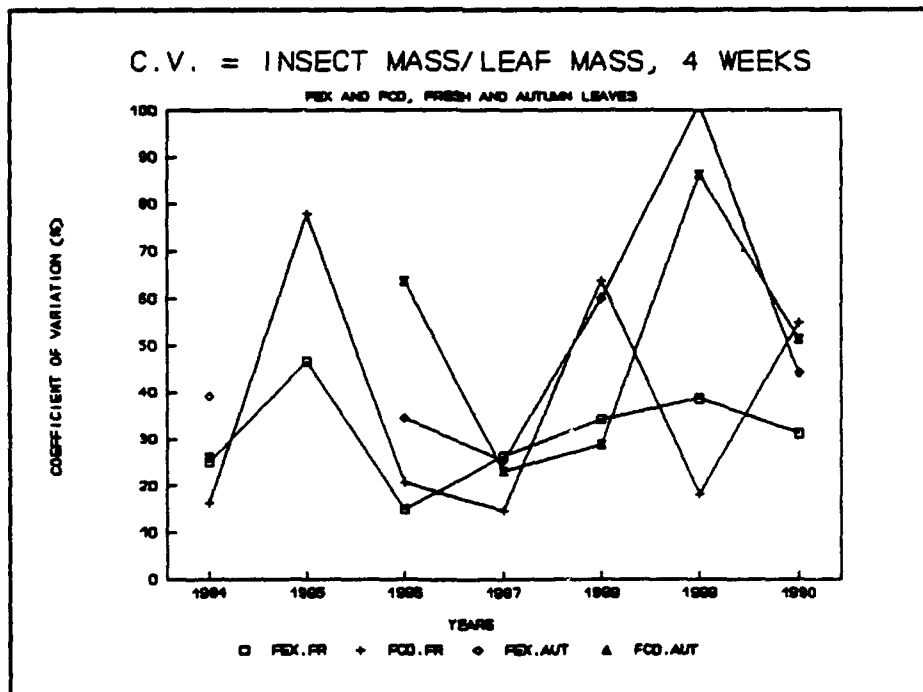


Figure 6.12B. Coefficient of Variation values for Total Insect Mass/Leaf Mass (mg./gm), 1984 - 1990. FEX Fresh (squares), FCD Fresh (pluses), FEX Autumn (diamonds), FCD Autumn (triangles).

TABLE 6.16
Two-Way ANOVA Tests, Total Insect Mass/Leaf Mass for
(A) Fresh and (B) Autumn Abscised Leaves
After 24 to 28 Days, 1984 - 1990

Source	d.f.	SS	MSS	F value
(A) FRESH				
Years	6	4131.046	688.508	26.397***
Site	1	16.430	16.430	0.630
Interaction	6	253.281	42.214	1.618
Error	84	2092.845	26.083	
(B) AUTUMN				
Years	5	7609.504	1521.901	12.853***
Site	1	578.634	578.634	4.887*
Interaction	5	4687.320	937.464	7.917***
Error	72	9996.803	118.406	

2. Changes in Mean Dry Weight per Individual (MDW/IND) for Three Species

Individuals of species found in sufficient numbers on leafpacks that grew during the autumn and winter seasons were monitored for possible changes in yearly growth rates at FEX, FCD, and in 1990, at FEX.LINE. Three species fulfilled those criteria: Ephemerella invaria, Ephemerella subvaria (mayfly collector-gatherers), and Isoperla transmarina (a predatory stonefly).

Changes in MDW/IND values for each species were plotted against cumulative degree days. The physiological time clock, cumulative degree days, began on the leafpack deployment day each year. Growth was related to reductions in daily water temperatures. Cumulative degree days showed that these species grew faster when water temperatures decreased rapidly in the fall and winter months (Figures 6.13A,B through 6.15A,B). Rather than being linear plots (as is the case for chronological time), these plots were exponential, with the fastest growth rates occurring when the lowest number of degree days accumulated between sampling dates. By late October through December, the waters had cooled and the leaf inputs were high for these collector-gatherers and predators. All three species emerge in the late spring-early summer each year (See Element 4, This Report.). The species had not attained their peak growth by the end of the leafpack experiments, but their accelerated rates of growth were obvious during the tenure of the leafpack experiments. If ELF exposure alters growth rates, one would expect the effects to be apparent in rate changes and/or in maximum size at emergence. This Element and Element 4 are

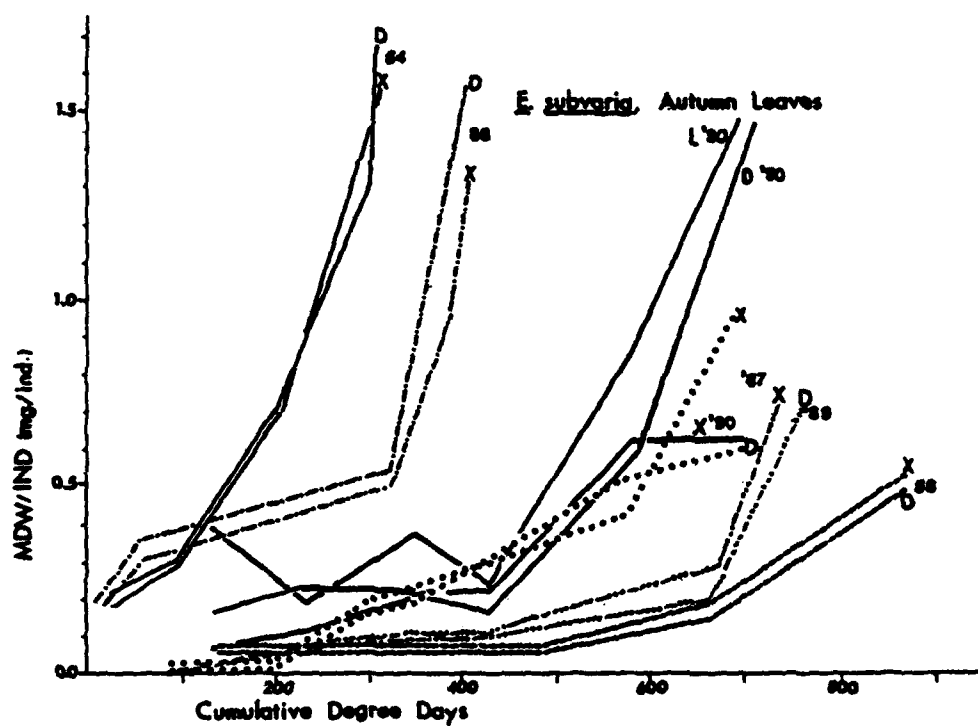
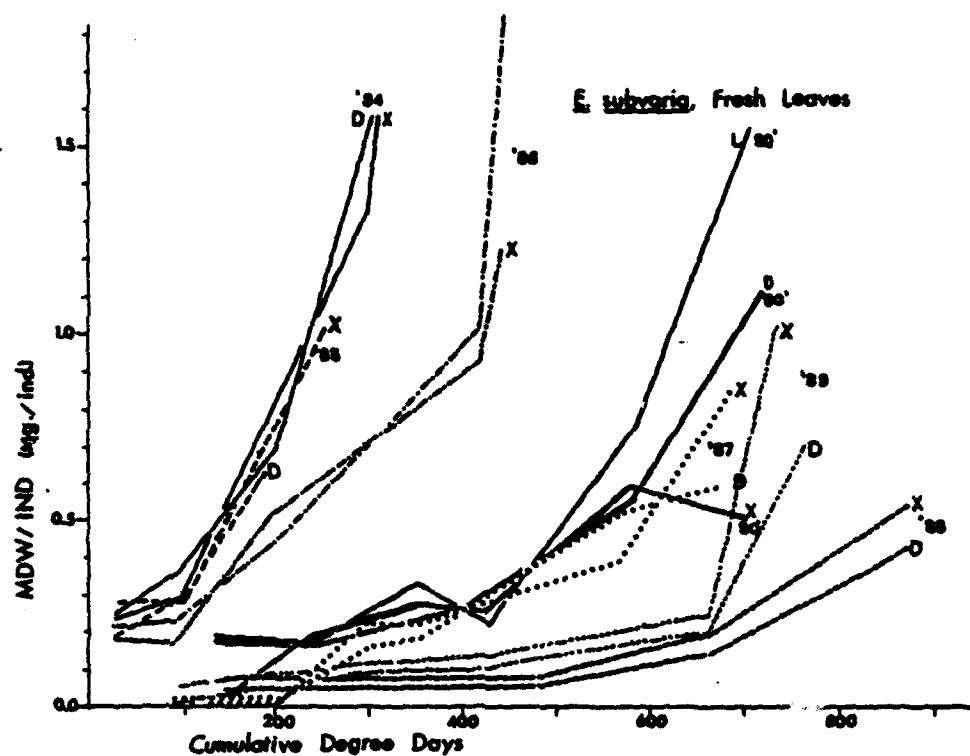
designed to identify any changes if they are statistically significant under natural conditions.

Table 6.17 presents results for ANCOVAS for growth of E. subvaria. The covariate is chronological time. Comparisons were made between FEX and FCD, year by year, and between FEX and FEX.LINE for 1990, which was the first year we initiated studies there.

TABLE 6.17
ANCOVAS for MDW/IND Changes for Ephemerella subvaria, FEX vs FCD and FEX vs. FEX.LINE. Fresh (A) and Autumn (B) Leaves, 1984 - 1990

F VALUES, SIGNIF.			F VALUES, SIGNIF.		
FEX VS. FCD FRESH	ADJ. MEANS	SLOPES	FEX VS. FCD AUT.	ADJ. MEANS	SLOPES
1984	0.688	.001	1984	6.728*	3.921
1985	1.951	.066			
1986	1.610	5.978*	1986	2.385	3.586
1987	1.761	2.299	1987	1.644	0.020
1988	1.797	1.555	1988	0.241	0.248
1989	2.169	12.356***	1989	0.996	0.386
1990	2.115	16.567***	1990	1.426	10.277**
FEX VS. FEX. LINE FRESH			FEX VS. FEX. LINE AUT.		
1990	4.433*	34.465***	1990	9.689**	13.214***

There were no significant differences in adjusted mean values for E. subvaria on fresh leaves; however, there were significant differences in slopes three times. In 1986 and in 1990, the slopes of the MDW/IND values were higher at FCD; in 1989, they were higher at FEX. Autumn leaf comparisons showed slope differences in 1990; the slope was higher at FCD.



Figures 6.13A, 6.13B. *Ephemerella subvaria* (A) Fresh Leaves, (B) Autumn Leaves. Changes in MDW/IND vs. Cumulative Degree Days. FEX, FCD, 1984-1990; FEX.LINE, 1990.

A comparison between FEX and FEX.LINE for 1990 shows that not only were the adjusted mean values significantly different (high y-intercept at FEX.LINE), but the slopes differed, with FEX.LINE values being higher. The new site has high primary productivity, as shown in Element 2 of this Report. We have found, thus far, more collector-gatherers in substrates at that site than at either of the other two sites. The preliminary data suggest that this new site may not be similar to either the FEX or the FCD site. Future data may support this contention.

Changes in MDW/IND for E. subvaria on autumn leaves showed an adjusted mean difference in 1984. The y-intercept was higher at FCD. In 1990, there were slope differences between the two sites, with FCD having the highest slope. A comparison between FEX and FEX.LINE for this treatment showed both a y-intercept and a slope difference between the two sites. FEX.LINE was higher in both cases.

Overall, it appears that FEX and FCD are similar with respect to 'growth' rates for this species. However, the new site appears to be much different from either of these sites with respect to this parameter. Future data will give us a better view as to whether differences will be statistically significant over time.

ANCOVAS for a second species, Ephemerella invaria on fresh leaves, showed that there were no significant adjusted mean value or slope differences between FEX and FCD and between FEX and FEX.LINE (Table 6.18).

TABLE 6.18
ANCOVAS for MDW/IND Changes for Ephemerella invaria, FEX vs FCD and FEX vs. FEX.LINE. Fresh (A) and Autumn (B) Leaves, 1984 - 1990

1. FEX vs. FCD

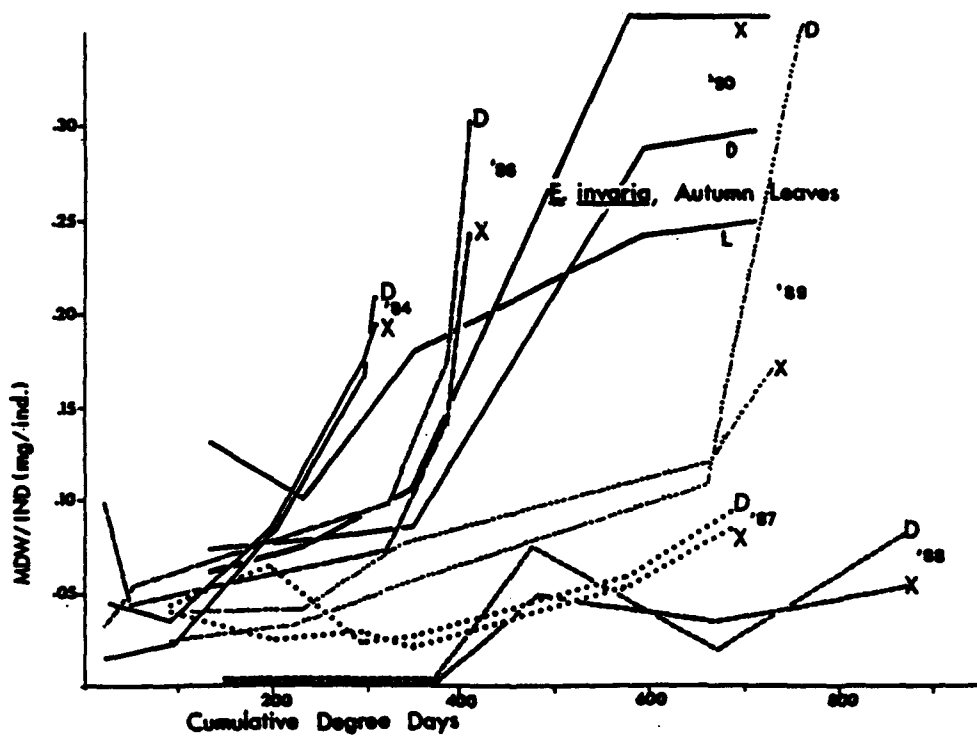
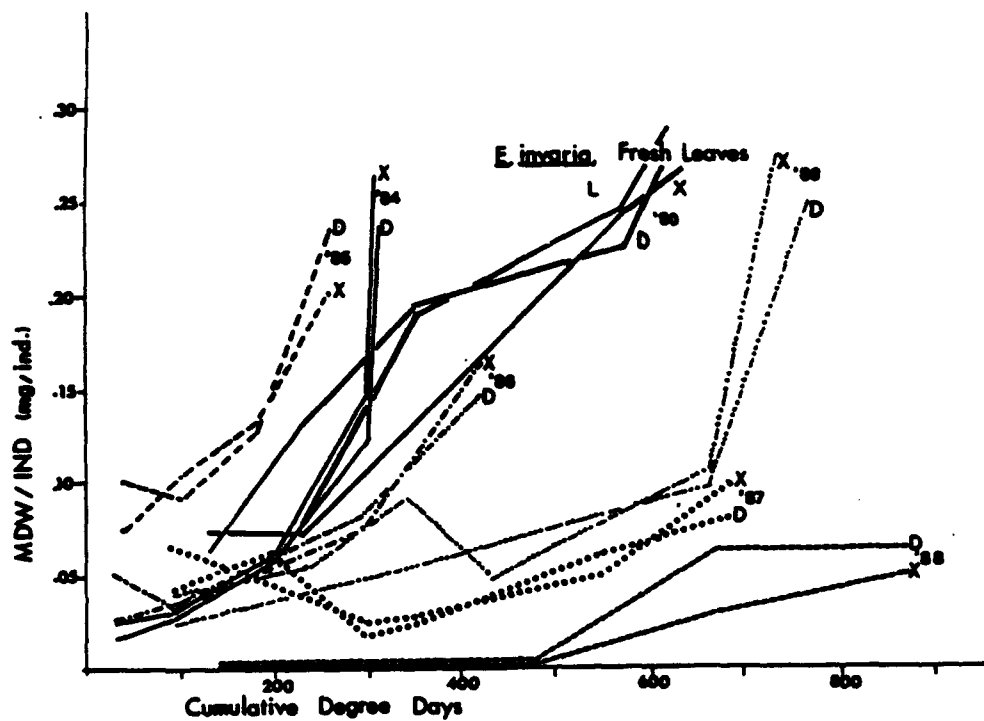
F VALUES, SIGNIF.

F VALUES, SIGNIF.

FRESH	ADJ. MEANS	SLOPES	AUT.	ADJ. MEANS	SLOPES
1984	0.503	.460	1984	0.121	0.410
1985	1.605	.434			
1986	2.332	.034	1986	0.673	6.230*
1987	1.400	.0079	1987	0.410	2.753
1988	1.332	.691	1988	0.226	4.081
1989	1.413	.048	1989	2.234	15.119***
1990	0.420	.116	1990	2.324	5.832*

2. FEX vs. FEX.LINE

1990	0.215	0.106	1990	0.463	12.522***
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Figures 6.14A, 6.14B. *Ephemerella invaria* (A) Fresh Leaves, (B) Autumn Leaves. Changes in MDW/IND vs. Cumulative Degree Days. FEX, FCD, 1984-1990; FEX.LINE, 1990.

Changes in MDW/IND for E. invaria on autumn leaves showed significant slope differences between FEX and FCD three times. In 1966 and in 1989 the slopes were higher at FCD; in 1990, they were higher at FEX. There were no differences in adjusted mean values. A comparison between FEX and FEX.LINE also showed slope differences; the slopes were greater at FEX. Overall, when significant slope differences between FEX and FCD occurred after ELF activation, they were higher at FCD twice and they were higher at FEX once. No pattern emerged for E. invaria's growth rates and ELF activation.

A predatory stonefly, Isoperla transmarina on fresh leaves, showed significant differences between FEX and FCD only once, Table 6.19. That was in 1984, and the adjusted mean values were higher at FCD (See Figure 6.15A). Changes in MDW/IND values for insects on autumn leaves showed a significant difference in slopes only once also; namely, in 1990 when the slopes were higher at FEX. A comparison between FEX and FEX.LINE for autumn leaves in 1990 also showed significant slope differences. Again, the slopes were higher at FEX (See Figure 6.15B).

TABLE 6.19

ANCOVAS for MDW/IND Changes for Isoperla transmarina, FEX vs FCD and FEX vs. FEX.LINE. Fresh (A) and Autumn (B) Leaves, 1984 - 1990

1. FEX vs. FCD

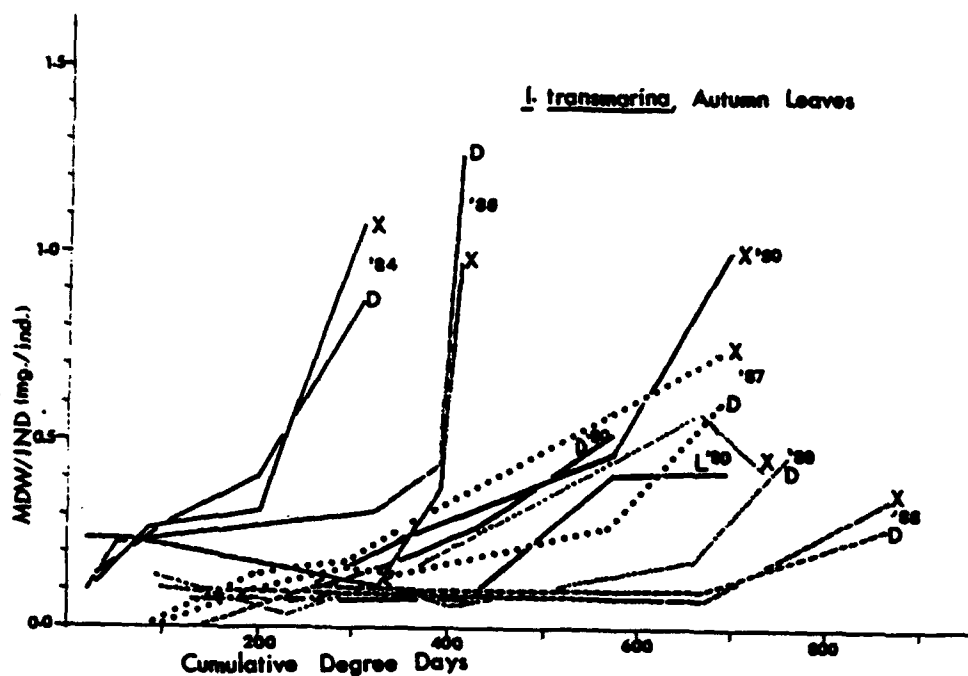
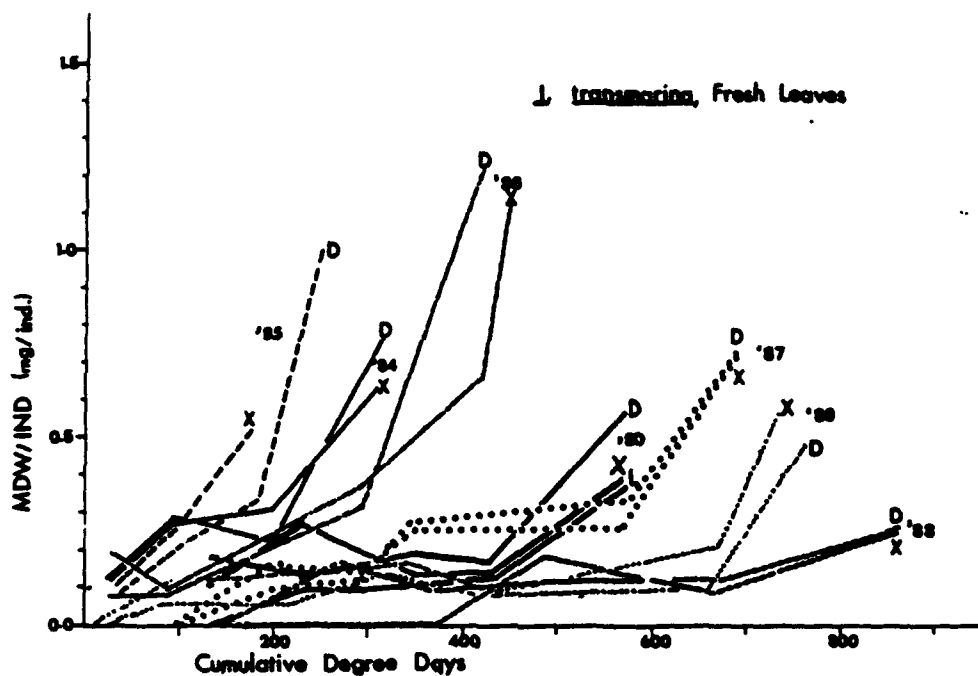
F VALUES, SIGNIF.

F VALUES, SIGNIF.

FRESH	ADJ. MEANS	SLOPES	AUT.	ADJ. MEANS	SLOPES
1984	4.329*	1.963	1984	0.284	0.247
1985	2.310	1.674			
1986	0.452	3.172	1986	0.431	1.328*
1987	0.002	0.380	1987	0.064	0.954
1988	Too few	data	1988	Too few	data
1989	0.003	2.183	1989	0.158	0.956
1990	0.282	0.374	1990	0.592	19.705***

2. FEX vs. FEX.LINE

1990	0.343	0.011	1990	2.003	13.560***
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Figures 6.15A, 6.15B. *Isoperla transmarina* (A) Fresh Leaves, (B) Autumn Leaves. Changes in MDW/IND vs. Cumulative Degree Days. FEX, FCD, 1984-1990; FEX.LINE, 1990.

Future Plans for this Element

Fresh leaf experiments will begin in late August each year, with collection of Day 28 samples being collected in mid-September. Autumn-abscised leaves were deleted from this element as of 1991. Identifications of insects on fresh leaves will be made for all collection dates in 1991 at the three sites. Owing to reductions in effort and the lag time of approximately one year in identifications, it is probable that only Day 28 samples for the 1992 year will be completed. Leaf losses will also be determined for that day, and if there is sufficient person power, processing coefficients will also be taken. (This requires five times the work effort in the initial stages of the monitoring study.) Changes in MDW/IND values for the three species described herein will also cease in 1992, as there is intense labor involved in the preparation, collection, and identification of seven replicates from three sites over six collection days.

Discussions as to how to handle ELF cumulative exposure data in terms of analysis will be made. It is possible that future analyses will include multiple regressions, using discharge, cumulative degree days, and possibly ELF cumulative exposure as the physical variables.

We will request cessation of the FEX.LINE site for this Element in 1992 unless there is a potential for long-term funding. This site appears dissimilar from the other two sites for which we have pre- and post-operational data.

Summary

Each year, fresh leaves were processed faster than autumn leaves. There were no site differences for fresh leaves or for autumn leaves when all the years were analyzed together. Fresh leaf losses in 1990 at the new site, FEX.LINE were less than the mean losses at the original sites; however, in 1991, losses among the sites were similar. The addition of this new site may have come too late in our monitoring program, even though its location relative to ELF ground field exposures is better than the original test site, FEX.

Coefficient of variation values for structural and community parameters of the insect community colonizing leaves were low after the leaves had been in the stream for four weeks. They were higher for earlier collections (Day 7, 14, and 21) and higher again for later collections (Day 50, 80). Therefore, we concentrated our statistical analyses on data from that collection period. Taxon diversity and evenness values were significantly higher at FEX even though they steadily decreased there and at FCD over the years. Leafpack experiments were initiated earlier after 1986 and this probably accounted for the year differences. The insect community colonizing leaves at FEX appears to be more diverse, but this higher diversity cannot be attributable to ELF fields. Taxon richness showed no consistent year or site pattern, but numbers of individuals did. They tended

to increase over the years in similar ways at both sites. Numerical dominance of chironomids also increased on both leaf treatments at the two sites over the years. Insect mass, adjusted to leaf mass, increased dramatically in 1989 and continued to increase on both treatments at FCD, but especially on autumn leaves. Most of the biotic parameters showed significant year differences but did not show site differences. Graphical analyses did not show that the year differences were associated with ELF activation. ANCOVAS on linear data were performed, using cumulative degree days and then ELF ground field cumulative exposure. Often there were y-intercept differences, but rarely were there slope differences. The use of ELF exposure as a covariate in ANCOVAS is questionable in that the data at the reference site were derived from those at the test site. Multiple regression analyses could be a better alternative in relating physical factors to our biotic parameters.

Mean growth rates of three species, Ephemerella subvaria, Ephemerella invaria, and Isoperla transmarina, were similar at the two sites each year of the study. There were a few times, however, when there were significant slope differences between the two sites. Because the sites oscillated over time with respect to slope differences, it is improbable that ELF activation is related. We compared results from the new site, FEX.LINE with those from our original site, FEX. There were significant differences, both in adjusted mean values and in slopes for E. subvaria on both leaf treatments. There were significant slope differences for the other two species on autumn leaves. The general characteristics of the new site, separate from its value of having a 10-fold difference in ELF exposure with respect to the control site, appear to be distinctly different from either the original test or control site. Our preliminary data support that biological viewpoint.

A summary of results for statistical analyses for this Element appears in two tables. Table 6.20 contains eight biotic parameters and four analyses. Leaf processing coefficients ($-k/\text{day}$) for each year from 1984 through 1991 were compared, using a two-tailed Student t-test. The remaining seven parameters include data for one collection period, four weeks' incubation data, from 1984 through 1990. Significant main effects and interactions are presented in the Two-way ANOVA column. Within site multiple regression analyses for looking at relative correlations among physical factors employed the independent variables years, discharge (disch), and cumulative degree days (CCD). These analyses were performed on leaf losses after four weeks. The highest partial F values were listed only if the R^2 values were greater than 0.50. ANCOVAS were performed on insect colonization data that were linear from 1986 - 1990 (after ELF activation) to analyze for effects of ELF cumulative exposure. Separate ANCOVAS were run for each of the two physical variables, cumulative degree days and ELF cumulative exposure.

TABLE 6.20
Summary of Statistics for Leaf Processing and Insect
Colonization on Fresh and Autumn *Alnus rugosa* Leaves

PARAMETER, TREATMENT	2 TAIL T TEST	2-WAY ANOVA	MULTIPLE REGRESSION	ANCOVA
-K/DAY, Fresh	n.s.			
-K/DAY, Autumn	n.s.			
After 4 Weeks				
Leaf losses, Fresh		Site,Yr,Inter.	FEX: Discharge	
Leaf losses, Aut.		Site	FEX: Discharge FCD: Year	
Diversity, Fresh		Site, Yr		Mean: CDD,ELF Slope: n.s.
Diversity, Autumn		Site, Yr		Mean: CDD,ELF Slope: n.s.
Evenness, Fresh		Years		Mean: CDD,ELF Slope: n.s.
Evenness, Autumn		Site,Yr,Inter.		Mean: ELF Slope: n.s.
Richness, Fresh		Yr, Interact.		
Richness, Autumn		Site, Yr		
# Individ., Fresh		Years		
# Individ., Aut		Years		
Midge Dom., Fresh		Years		Mean: CDD,ELF Slope: n.s.
Midge Dom., Aut.		Yr, Interact		Mean: CDD,ELF Slope: CDD
Insect Mass, Fresh		Years		
Insect Mass, Aut.		Site,Yr,Inter.		

Table 6.21 gives a summary of year by year comparisons between FEX and FCD with respect to changes in mean dry weight per individual (MDW/IND) for three insect taxa. Leaf treatments were analyzed separately. When there were no significant differences between FEX and FCD, that was noted with a zero (0); when FEX was higher than FCD, it was noted with a plus (+); and when FEX was lower than FCD, it was noted with a minus (-). Comparisons between FEX and FEX.LINE were also made for 1990 data. The same notation was used.

TABLE 6.21
Ancovas for Testing Differences Between Sites for
Changes in MDW/IND of Three Insect Species

A. FEX vs. FCD

FRESH LEAVES				AUTUMN LEAVES		
Year	<u>Ephemera</u> <u>subvaria</u>	<u>Ephemera</u> <u>invaria</u>	<u>Isoptera</u> <u>transmarina</u>	<u>E.</u> <u>subvaria</u>	<u>E.</u> <u>invaria</u>	<u>L.</u> <u>trans.</u>
1984	0	0	0	0	0	0
1985	0	0	0	0		
1986	-	0	0	0	-	0
1987	0	0	0	0	0	0
1988	0	0		0	0	
1989	+	0	0	0	-	0
1990	-	0	0	-	+	+

B. FEX vs. FCD

FRESH LEAVES				AUTUMN LEAVES		
Year	<u>E. subvaria</u>	<u>E. invaria</u>	<u>Iso. trans</u>	<u>E. sub.</u>	<u>E. inv.</u>	<u>Iso. trans.</u>
1990	-	0	0	-	+	-

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Element 7 - Fish Community Composition and Abundance

Changes from workplan: Data analysis design structured in this manner; pre-operational years (1983-1985), transitional years (1986-1989), and post-operational years (1990-1991). The primary analyses presented in this report compare pre-operational years with transitional and post-operational years. Also, in 1991 movement of all fish species was monitored at FEN, a new site 400m upstream of FEX.

The use of scales for age and growth analysis of common shiners, creek chubs, and white suckers has been discontinued due to difficulties in obtaining accurate age estimates from scales. Length frequency distribution analysis will replace the scale method for age and growth determination. However, due to the lack of standard methods for determining age and growth from length frequency distributions this portion of the report is not completed. The initial results of the analysis are included in this report.

Objectives

The overall goal of this element is to determine the effects of the Navy's ELF project on the fish community structure and movement characteristics in the Ford River. Our specific objectives are to determine: 1) The fish community species composition and relative abundance at FEX and FCD; 2) The age, length/weight characteristics, growth, and condition of the species most represented in the gear (burbot, common shiners, creek chubs and white suckers) excluding brook trout (see Element 8); 3) The relative mobility of the fish community excluding brook trout (see Element 8) in the Ford River.

Materials and Methods

A. Community Composition and Abundance

Fish were caught using fyke nets fished in tandem, one facing upstream and one facing downstream, at FEX and FCD. In addition, two 1/2 inch wire mesh weir sites (FCU and TM), in a configuration similar to Hall's (1972), were fished in an effort to determine the movement patterns of fish marked at FEX and FCD. To determine whether brook trout were capable of passing underneath the antenna, a new net site (FEN) was established approximately 400m upstream of FEX in 1990. All species were monitored at this site in 1991. Nets and weirs were fished continuously from May 17 to July 19 with the exception of 5 days in early June and 6 days in early July when discharge levels were above gear and

personnel capabilities to fish. When catch rates were low (< 1 fish/day) from July 19 through September 15, the gear was fished 4 days/week (deployed on Monday and removed on Friday). The gear at FEN was fished continuously from June 11 through July 2. All gear was checked every 24 hours. The number of sampling days for each year is reported in Figure 7.1.

All fish were enumerated, measured for total length, weighed and marked by a fin clip distinctive for each study site. The fish were then returned to the water upstream or downstream from the station in their original direction of travel. At FEN, FCU, and TM, species other than brook trout were enumerated and examined for fin clips only.

B. Fish Community Mobility

Movement patterns for the dominant species in the Ford River were monitored by observing the frequency of recapture of fin clipped fish in our gear. Fish recaptured at a site other than the original marking site were measured for total length and given an additional fin clip specific to the recapture site.

Results and Discussion

A. Species composition

Seventeen species from five orders and ten families were collected at FEX in 1991 (Table 7.1). No new species were observed in 1991 at FEX. Differences in the overall FEX species composition between years can be attributed to changes in the catch of rare species.

The catch at FCD in 1991 consisted of nineteen species from ten families and five orders (Table 7.2). No new species were added to the species list at FCD in 1991. Again, as in the FEX samples, the only changes in the species composition occurred in the rare species which occur infrequently.

As in the past, the species composition was slightly higher at FCD than at FEX which is a result of species infrequently captured. Overall the two sites continued to be similar in species composition and consistent within a site over the duration of the study.

B. Species abundance

The numeric catch at FEX was dominated by 5 species with the majority of the individuals from the cyprinid family (Figure 7.2). Common shiner percent catch by number was the highest at 58.4% and was above their mean for all years.

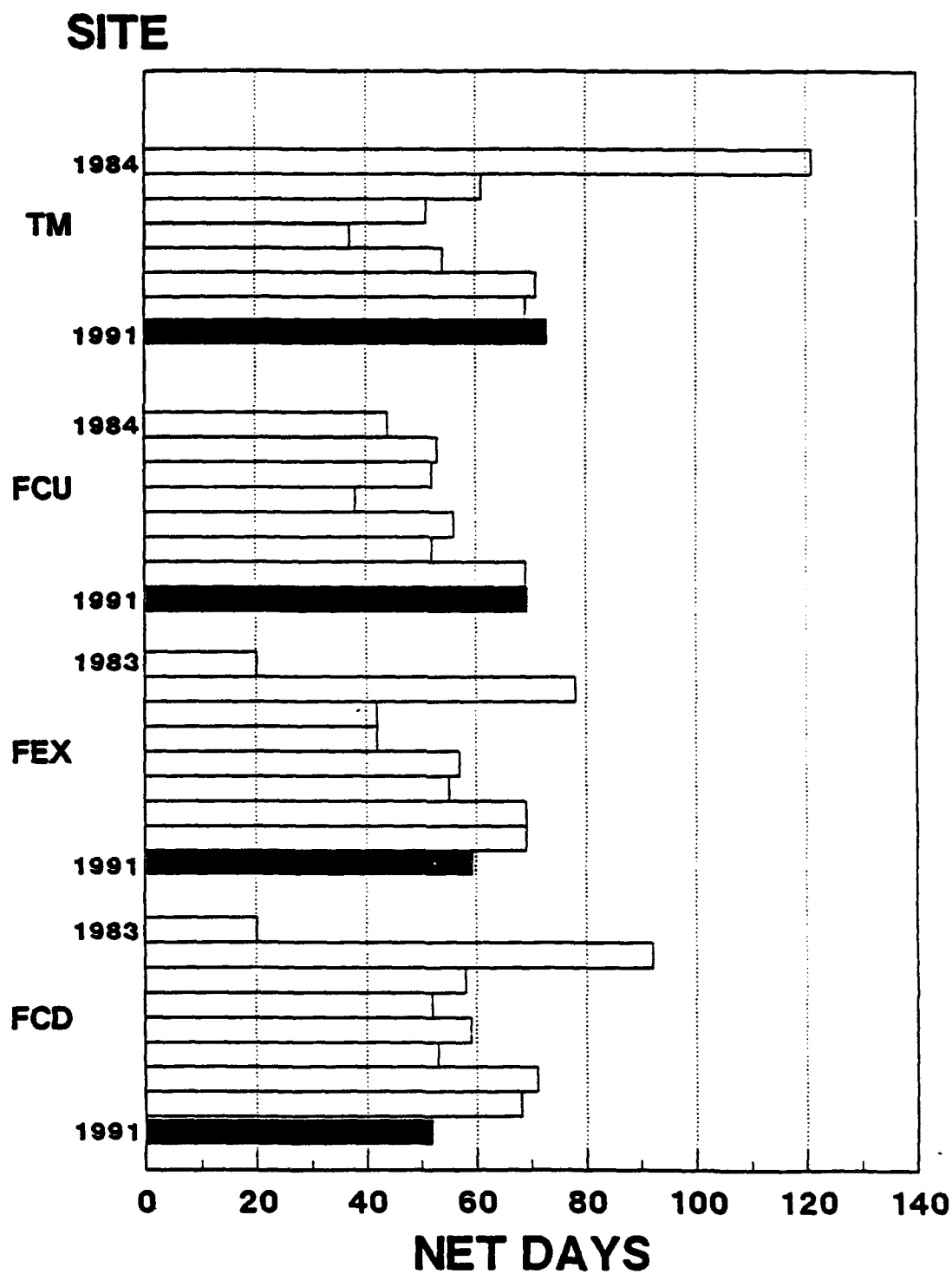


Figure 7.1. Net days at all ELF study sites from 1983-1990.

Table 7.1. Fish species collected at FEX from May 1983 through September 1991 using 1/2" mesh fyke nets. Scientific names are from Robins et al. 1980.

Scientific Name	Common Name	1983	1984	1985	1986	1987	1988	1989	1990	1991
Cypriniformes										
Catastomidae										
<i>Catostomus commersoni</i> (Lacepede)	White sucker	x	x	x	x	x	x	x	x	x
<i>Hypentelium nigricans</i> (Lesueur)	Northern hog sucker			x						
Cyprinidae										
<i>Notropis cornutus</i> (Mitchill)	Common shiner	x	x	x	x	x	x	x	x	x
<i>Rhinichthys atratulus</i> (Hermann)	Blacknose dace	x	x		x	x	x	x	x	x
<i>Rhinichthys cataractae</i> (Valenciennes)	Longnose dace	x	x	x	x	x	x	x	x	x
<i>Semotilus atromaculatus</i> (Mitchill)	Creek chub	x	x	x	x	x	x	x	x	x
<i>Semotilus margarita</i> (Cope)	Pearl dace	x	x		x	x	x	x	x	x
Gadiformes										
Gadidae										
<i>Lota lota</i> (Linnaeus)	Burbot	x	x	x	x	x	x	x	x	x
Perciformes										
Centrarchidae										
<i>Ambloplites rupestris</i> (Rafinesque)	Rock bass		x	x	x	x	x	x	x	x
<i>Micropterus dolomieu</i> (Lacepede)	Smallmouth bass		x		x	x	x			x
<i>Micropterus salmoides</i> (Lacepede)	Largemouth bass		x							
<i>Lepomis gibbosus</i> (Linnaeus)	Pumpkinseed					x				
Cottidae										
<i>Cottus bairdi</i> (Girard)	Mottled sculpin	x	x	x	x	x	x	x	x	x
Percidae										
<i>Percina maculata</i> (Girard)	Blackside darter	x	x	x	x		x	x	x	x
Petromyzontiformes										
Petromyzontidae										
<i>Ichthyomyzon fossor</i> (Reighard and Cummins)	Northern brook lamprey			x						x
<i>Petromyzon marinus</i> (Linnaeus)	Sea Lamprey		x	x	x					

Table 7.1 continued

Scientific Name	Common Name	FEX						
		1993	1994	1995	1996	1997	1998	1999
Salmoniformes								
Esockidae								
<i>Esox lucius</i> (Linnaeus)	Northern pike	x	x	x	x	x	x	x
Salmonidae								
<i>Oncorhynchus tshawytscha</i> (Walbaum)	Coho salmon					x	x	x
<i>Oncorhynchus mykiss</i>	Rainbow trout				x	x	x	x
<i>Salvelinus fontinalis</i> (Mitchill)	Brook trout	x	x	x	x	x	x	x
Umbridae								
<i>Umbra limi</i> (Kirtland)	Central mudminnow	x	x	x	x	x	x	x
Siluriformes								
Ictaluridae								
<i>Ictalurus nebulosus</i> (Lesueur)	Brown bullhead						x	x

Table 7.2. Fish species collected at FCD from May 1983 through September 1991 using 1/2" mesh fyke nets. Scientific names are from Robins et al. 1980.

Scientific Name											Common Name											FCD									
Clupeiformes											Alewife																				
Clupeidae																															
Alosa pseudoharengus (Wilson)																															
Cypriniformes											White sucker																				
Catostomidae											Northern hog sucker																				
Cyprinidae																															
Nocomis biguttatus (Kirtland)											Hornyhead chub																				
Notemigonus crysoleucas (Mitchill)											Golden shiner																				
Notropis cornutus (Mitchill)											Common shiner																				
Pimephales promelas (Rafinesque)											Fathead minnow																				
Phoxinus phoxinus (Cope)											Northern redbelly dace																				
Rhichthys atratulus (Hermann)											Blacknose dace																				
Rhichthys cataractae (Valenciennes)											Longnose dace																				
Semotilus atromaculatus (Mitchill)											Creek chub																				
Semotilus margaritis (Cope)											Pearl dace																				
Cyprinus carpio (Linnaeus)											Carp																				
Gadiformes																															
Gadidae																															
Lota lota (Linnaeus)											Burbot																				
Perciformes																															
Centrarchidae																															
Ambloplites rupestris (Rafinesque)											Rock bass																				
Lepomis gibbosus (Linnaeus)											Pumpkinseed																				
Lepomis macrochirus (Rafinesque)											Bluegill																				
Micropterus dolomieu (Lacepede)											Smallmouth bass																				
Micropterus salmoides (Lacepede)											Largemouth bass																				
Cottidae																															
Cottus bairdi (Girard)											Mottled sculpin																				
Percidae																															
Percina maculata (Girard)											Blackside darter																				

Table 7.2 continued.

Scientific Name	Common Name	FCD						
		1983	1984	1985	1986	1987	1988	1989
Petromyzontiformes								
Petromyzontidae								
<u>Petromyzon marinus</u> (Linnaeus)	Sea lamprey	x	x	x	x	x	x	x
Salmoniformes								
Esocidae								
<u>Esox lucius</u> (Linnaeus)	Northern pike	x	x	x	x	x	x	x
Salmonidae								
<u>Oncorhynchus kisutch</u> (Walbaum)	Coho salmon						x	
<u>Oncorhynchus mykiss</u>	Rainbow trout						x	
<u>Salvelinus fontinalis</u> (Mitchell)	Brook trout	x	x	x	x	x	x	x
Umbridae								
<u>Umbra limi</u> (Kirtland)	Central mudminnow		x	x	x	x	x	x
Siluriformes								
Ictaluridae								
<u>Ictalurus punctatus</u> (Lesueur)	Brown bullhead			x			x	x

BT=Brook Trout BUR=Burbot CS=Common Shiner
 CC=Creek Chub WS=White Sucker OTH=Other

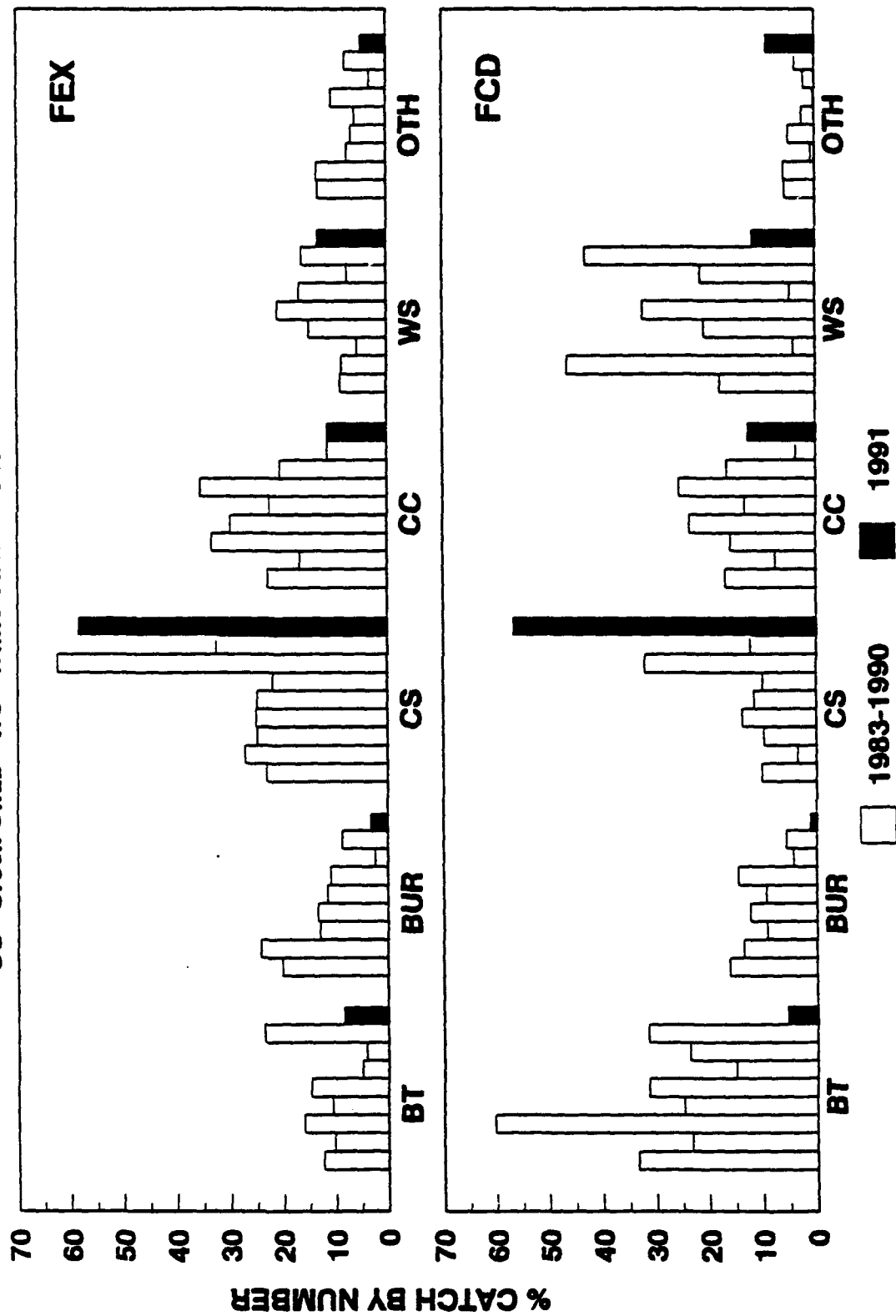


Figure 7.2. Percent catch by number at FEX and FCD from 1983 through 1991.

combined (33.3%). White suckers made up 13.3% of the catch which is above the mean over all years combined (12.5%). Creek chub percent catch by number (11.9%) in 1991 was below the mean for all years combined (22.6%). Brook trout (8.2%) percent catch by number in 1991 at FEX was below the mean (11.6%) for all years. Burbot percent catch by number decreased from 8.7% in 1990 to 3.2% in 1991 which is well below 12.8%, the mean for all years combined.

The relative numeric abundance of the catch at FCD was dominated by the same species (common shiners) as at FEX (Figure 7.2). Common shiners made up 57.4% of the total catch at FCD which was well above 43.3%, the average for all years combined. The percent of creek chubs in the catch was 13.6% which was down from the mean for all years combined (24.2%). The white sucker component in 1991 consisted of 12.6% of the total number of fish and was slightly above the mean for all years combined (11.7%). Burbot (1.6%) and brook trout (5.8%) catch in 1991 decreased when compared to their means over all years (5.7% and 8.1% respectively).

To analyze the total catch by numbers by year, the data for each species were first weighted by the number of net days per site per year. There were no significant differences between FEX and FCD in total numbers caught when these values were adjusted by the number of net days (Table 7.3). In addition, significant correlations existed between FEX and FCD (Spearman Rank Correlation, $p < 0.05$) in numeric abundance of each species adjusted by the number of net days in 1985 through 1991 (Table 7.4). The numeric catch in 1983, 1984, and 1990 were not correlated. To examine the correlation results for all 9 years, a X^2 test ($\alpha = 0.05$) from Sokal and Rohlf (1969, pg 623) was used. This test assumes that each year represents an independent test of the overall hypothesis of no similarity between sites and confirmed the similarity between sites ($X^2 = 52.73$, $df = 18$, $p < 0.05$).

A BACI (Stewart-Oaten and Murdoch, 1986) analysis was used to test pre-operational (1983-1985) versus transitional (1986-1989) numeric catch data. An analysis was conducted for each of the species. Individual species data were log transformed and a 2 sample t-test performed using the difference between FCD and FEX. No evidence of a difference between the pre-operational and transitional period was observed in the numeric catch data for any of the species (Table 7.5a). Further, treating each of the 6 species categories as an independent trial, yielded no evidence of a difference between the pre-operational and transitional periods (Sokal and Rohlf X^2 test (1969, pg 623) of BACI results in Table 7.5a; $X^2 = 3.61$, $df = 12$, $p > 0.05$). BACI analysis was also used to test pre-operational and post-operational numeric catch data (Table 7.5a). No significant difference was found to exist ($X^2 = 14.01$, $df = 12$, $p > 0.05$).

Table 7.3. Chi Square analysis by year of the numeric catch (adjusted for the number of net days) between FEX and FCD from 1983 through 1991.

YEAR	1983	1984	1985	1986	1987	1988	1989	1990	1991
X ²									
VALUE	3.98	4.30	1.30	1.44	5.96	6.04	1.18	4.06	0.69
<hr/>									
X ² _{5,0.05}	=11.1 NONE SIG.								

Table 7.4. Spearman Rank Correlation Coefficients for the numeric catch (adjusted for the number of net days) at FEX and FCD from 1983 through 1991.

YEAR	CORRELATION COEFFICIENT	PROBABILITY ¹
1983	0.543	0.266
1984	0.200	0.704
1985	0.886*	0.019
1986	0.886*	0.019
1987	0.828*	0.041
1988	0.828*	0.041
1989	0.943*	0.005
1990	0.486	0.329
1991	0.886*	0.019

* INDICATES SIGNIFICANT CORRELATION EXISTS

¹ Used in Sokal and Rohlf (1969) X² test to examine correlation results over the 8-year period, where:

$$X^2_{calc} = -2\text{Sum}(\ln P) = 52.73; \text{df}=2*(\text{number of tests})=18$$

$$X^2_{18,0.05} = 28.9$$

and P = the probability associated with the correlation coefficient.

Table 7.5a. BACI analysis using 2 sample t-test on log transformed data to test pre-operational (1983-1985) vs. transitional (1986-1989) and pre-operational vs. post-operational (1990-1991) numeric catch data.

SPECIES	Pre vs. Trans		Pre vs. Post	
	$t_{calc.}$	Probability ¹	$t_{calc.}$	Probability ²
Burbot	0.457	0.667	1.406	0.254
Brook Trout	0.673	0.531	0.638	0.569
Creek Chub	1.004	0.361	1.657	0.196
Common Shiner	0.773	0.474	1.363	0.266
White Sucker	0.572	0.592	0.227	0.835
Other	0.848	0.435	1.964	0.144

$t_{5,0.05} = 2.57$ None Sig.

¹Sokal and Rohlf X^2 test of BACI results (see Table 7.4 for explanation of method): $X^2_{calc.} = 3.61$, $X^2_{12,0.05} = 21.0$.
Not significant.

²Sokal and Rohlf X^2 test of BACI results: $X^2_{calc.} = 14.01$, $X^2_{12,0.05} = 21.0$.
Not significant

Table 7.5b. BACI one-way ANOVA on log transformed data to test pre-operational vs. transitional vs. post-operational numeric catch data.

SPECIES	$F_{2,6}$	Probability ¹
Burbot	2.23	0.188
Brook Trout	0.24	0.793
Creek Chub	1.68	0.264
Common Shiner	1.34	0.329
White Sucker	0.23	0.800
Other	2.25	0.187

¹Sokal and Rohlf X^2 test: $X^2_{calc.} = 12.49$, $X^2_{12,.05} = 21.0$
None significant

Furthermore, a one-way ANOVA of the log transformed data was used to test pre-operational, transitional, and post-operational periods (Table 7.5b). There was no evidence of any difference in numeric catch among the three periods ($X^2=12.49$, $df=12$, $p>0.05$). Overall, there were no significant between site differences or between period differences in catch by number over all years of the study despite species showing variable abundance from year to year.

Percent catch by biomass showed different trends in community structure than the catch by number at both sites (Figure 7.3). White suckers displayed the highest percent catch by biomass at FEX encompassing 35.1% of the catch. This was well above 25.0% which was the mean for all years combined at this site. Brook trout percent catch by biomass was second highest at FEX in 1991 at 23.3% which was below the mean for all years combined (29.6%). Percent catch by biomass for common shiners was above the average for all years (23.2%, mean = 14.0%). Creek chub (8.3%) and burbot percent catch by biomass (3.5%) at FEX in 1991 were well below the mean for all years combined (14.6% and 19.8% respectively).

The catch biomass at FCD showed similar trends as FEX with the same five species dominating the catch (Figure 7.3). Brook trout and common shiners were the dominant species making up 24.2% and 23.0% of the biomass respectively, and were above the means over all years combined (23.6% and 20.7%). White sucker (22.2%) and creek chub (8.9%) percent catch by biomass was below the mean for all years combined (25.7% and 17.6% respectively). Burbot made up 6.9% of the catch biomass in 1991 at FCD which was slightly above the average for all years (5.6%).

The cyprinid biomass at FCD continued to be higher than at FEX. To analyze the species biomass data, biomass estimates were first adjusted for the number of net days. FEX and FCD displayed similar patterns in 4 of the 9 years (Table 7.6; Spearman Rank Correlation, $p<0.05$). However, using the X^2 test described by Sokal and Rohlf (1969, pg 623), over the 9-year period of the study FEX and FCD had similar catch-by-biomass patterns ($X^2=49.36$, $df=18$, $p>0.05$). No evidence of any difference between pre-operational and transitional biomass data for any species was observed (BACI analysis, 2 sample t-test, $\alpha=0.05$) (Table 7.7a). A test of the BACI analysis confirmed the result (Sokal and Rohlf X^2 test, $X^2=2.08$, $df=12$, $p>0.05$). A BACI analysis of the pre-operational and post-operational biomass data detected a significant difference in the biomass of burbot between the two periods (Table 7.7a). However, there were no significant differences between the biomass of all the other species (Table 7.7a). In addition, a one-way

BT=Brook Trout BUR=Burbot CS=Common Shiner
 CC=Creek Chub WS=White Sucker OTH=Other

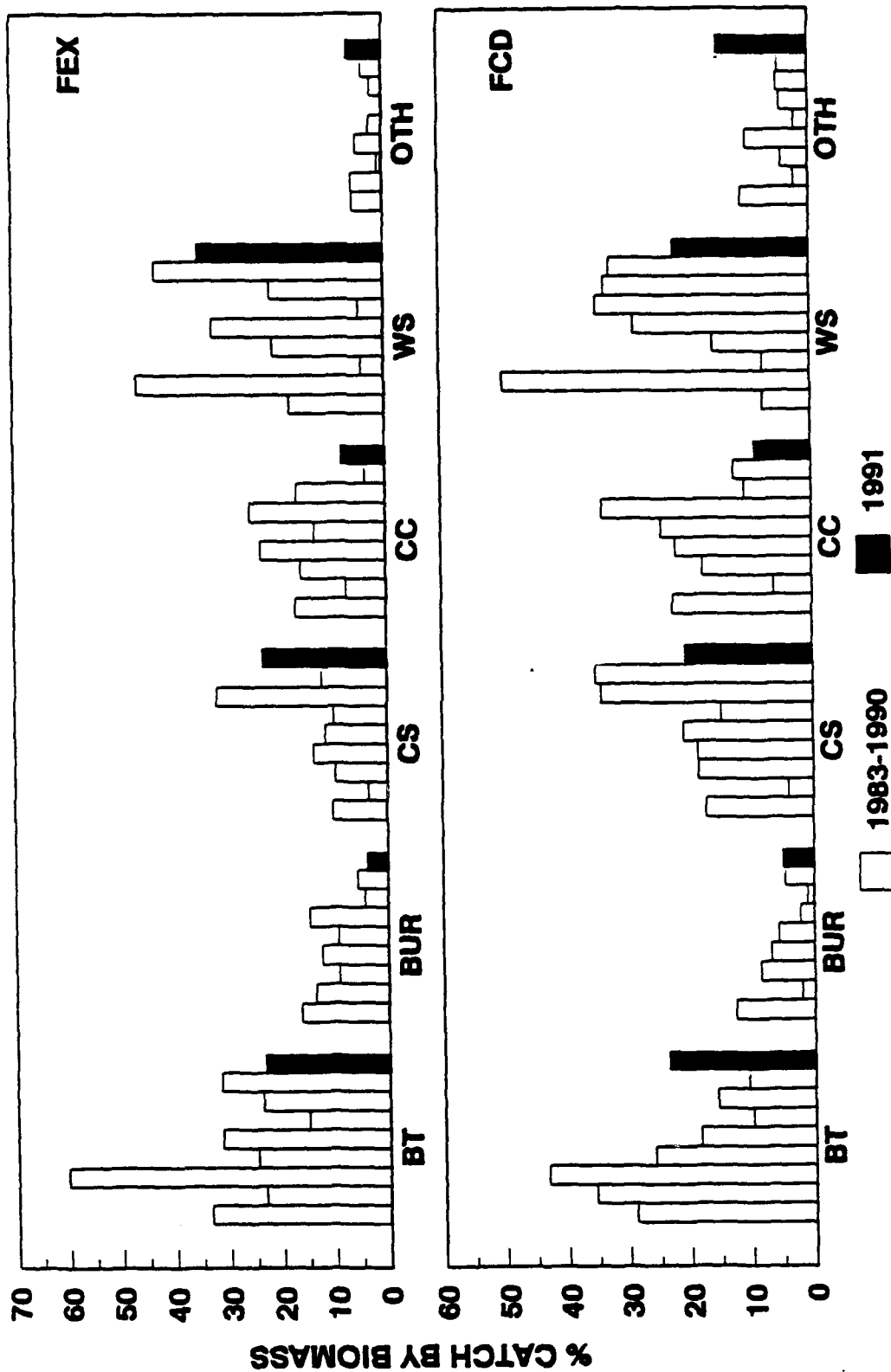


Figure 7.3. Percent catch by biomass at FEX and FCD from 1983 through 1991.

Table 7.6. Spearman Rank Correlation Coefficients for catch by biomass (adjusted for the number of net days) at FEX and FCD from 1983 through 1991.

YEAR	CORRELATION COEFFICIENT	PROBABILITY ¹
1983	0.600	0.208
1984	0.786*	0.064
1985	0.886*	0.019
1986	0.657	0.156
1987	0.829*	0.041
1988	0.671	0.144
1989	0.943*	0.005
1990	0.600	0.208
1991	0.771	0.072

* INDICATES SIGNIFICANT CORRELATION EXISTS

¹Sokal and Rohlf X^2 test: $X^2_{calc.} = 49.36$, $X^2_{18,0.05} = 28.9$.
Significant. See Table 7.4 for further detail.

Table 7.7a. BACI analysis using 2 sample t-test on log transformed data to test pre-operational (1983-1985) vs. transitional (1986-1989) and pre-operational vs. post-operational (1990-1991) catch by biomass data.

SPECIES	$t_{calc.}$	Probability ¹	$t_{calc.}$	Probability ²
Burbot	0.902	0.930	3.171	0.050
Brook Trout	0.230	0.827	0.044	0.968
Creek Chub	0.309	0.770	1.290	0.287
Common Shiner	1.464	0.203	1.342	0.272
White Sucker	0.116	0.912	0.170	0.876
Other	0.227	0.829	1.058	0.368

$t_{5,0.05} = 2.57$ * Significant

¹Sokal and Rohlf X^2 test of BACI results (see Table 7.4 for explanation of method): $X^2_{calc.} = 2.08$, $X^2_{12,0.05} = 21.0$.

Not Significant.

²Sokal and Rohlf X^2 test of BACI results: $X^2_{calc.} = 13.42$, $X^2_{12,0.05} = 21.0$

Not significant.

Table 7.7b. BACI one way ANOVA on log transformed data to test pre-operational vs. transitional vs. post-operational catch by biomass data.

SPECIES	$F_{2,6}$	Probability ¹
Burbot	8.64*	0.017
Brook Trout	0.04	0.960
Creek Chub	1.15	0.377
Common Shiner	1.68	0.263
White sucker	0.05	0.956
Other	0.64	0.561

$F_{2,6,0.05} = 5.14$ *significant

¹Sokal and Rohlf X^2 test: $X^2_{calc.} = 14.10$, $X^2_{12,0.05} = 21$.

Not significant

ANOVA of the pre-operational, transitional, and post-operational percent catch by biomass data revealed a difference in the biomass of burbot among the three periods. There were no significant differences in percent catch by biomass for all the other species (Table 7.7b).

Shannon-Weaver diversity values for 1991 were similar to the lower values observed in 1988 through 1990 (Table 7.8). A Spearman Rank Correlation test ($r_s=0.80$, $p<0.05$) indicated a similar pattern in the Shannon-Weaver index for FCD and FEX from 1983-1991. A BACI analysis was done comparing the pre-operational (1983-1985) and transitional periods (1986-1989). A two-sample t-test was used to compare the log-transformed difference between the yearly FCD and FEX index values. No significant difference between the two periods was found ($t=0.912$, $df=5$, $p>0.05$). A BACI analysis of pre-operational and post-operational also revealed no significant differences ($t=0.335$, $df=5$, $p>0.05$) between the Shannon-Weaver diversity values for the pre-operational and the post-operational periods.

Diversity values have decreased in a fairly linear fashion over the course of the study according to the following relationships:

$$\begin{aligned}\text{FEX: Index} &= 10.80 - 0.104 (\text{Year}) & r^2 &= 0.72 \\ \text{FCD: Index} &= 9.52 - 0.089 (\text{Year}) & r^2 &= 0.63.\end{aligned}$$

The rate of decrease (slope) of diversity at FEX and FCD was not significantly different (ANCOVA, $F_{1,14}=0.1709$, $p>0.05$). In addition, the intercepts were found to be similar (ANCOVA, $F_{1,15}=0.001$, $p>0.05$). Overall, diversity values continued to be similar between sites and should be a sensitive indicator of ELF effects during operational years.

C. Catch Statistics

Catch rates at both FEX and FCD showed the large amount of variance for all species one would expect from catches having a negative binomial distribution. White suckers, common shiners and creek chubs all have high spring - early summer catch rates because of spawning movements. Brook trout catch rates are also high in the late spring - early summer but this is attributed to water temperatures increasing above optimal (see Element 8, Brook Trout Movement Characteristics). The size distribution of the species commonly caught can be seen in Figure 7.4(a-l)

Mean lengths of the dominant species at FEX have remained fairly constant through all years (Figure 7.5). Brook trout showed a slight decrease in mean length from 1983-1988 (mean = 190.6 mm), but mean length in 1989

Table 7.8. Mean daily Shannon-Weaver diversity index values for FEX and FCD from 1983 through 1991.

YEAR	FEX	FCD
1983	2.16 \pm 0.26	1.94 \pm 0.36
1984	2.20 \pm 0.56	2.03 \pm 0.33
1985	1.97 \pm 0.39	2.15 \pm 0.33
1986	1.62 \pm 0.48	1.87 \pm 0.31
1987	2.13 \pm 0.18	2.11 \pm 0.45
1988	1.62 \pm 0.34	1.54 \pm 0.27
1989	1.41 \pm 0.36	1.47 \pm 0.43
1990	1.42 \pm 0.58	1.32 \pm 0.27
1991	1.47 \pm 0.32	1.56 \pm 0.33

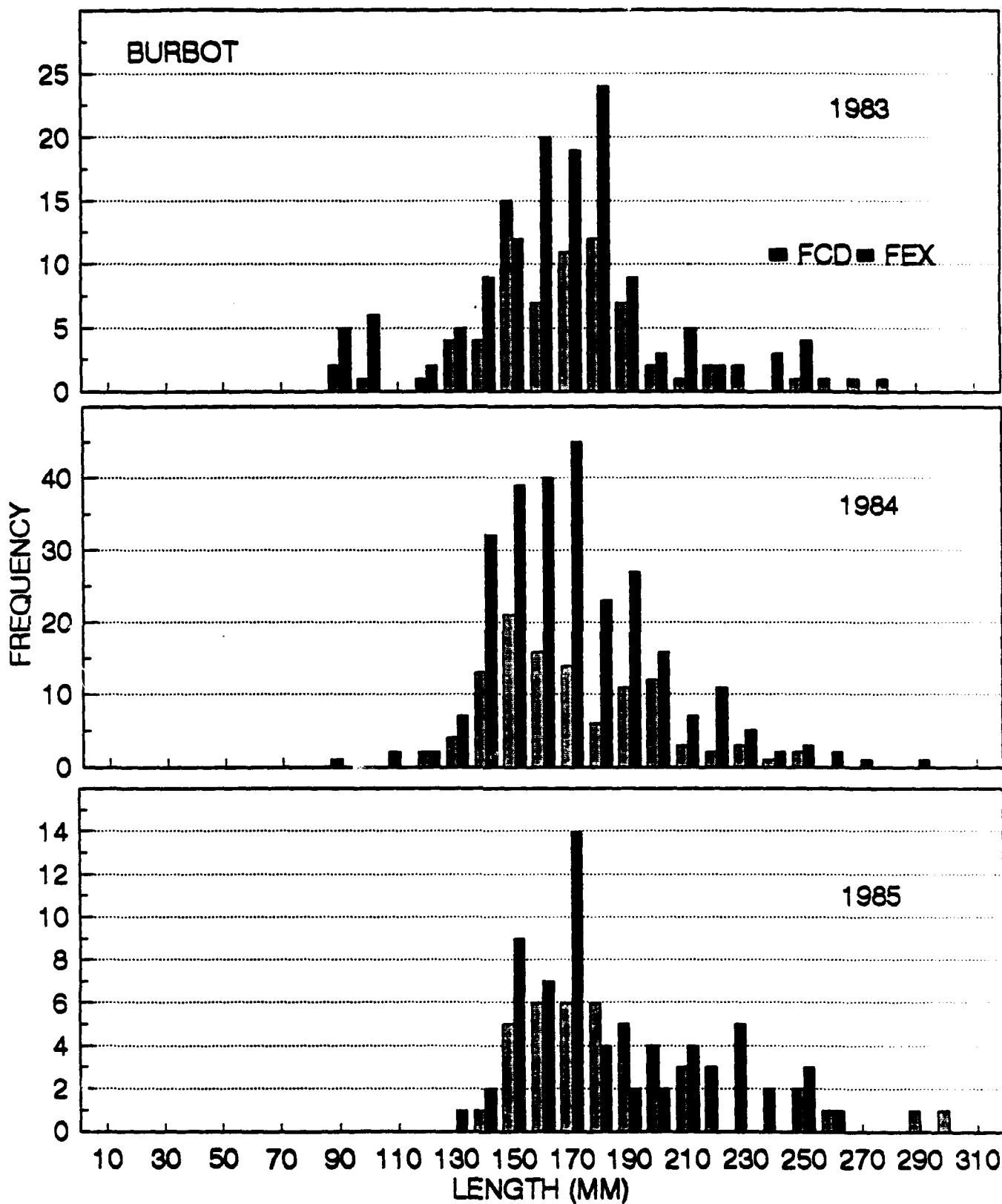


Figure 7.4a. Length frequency distribution of annual catch of burbot at FCD and FEX from 1983 to 1985.

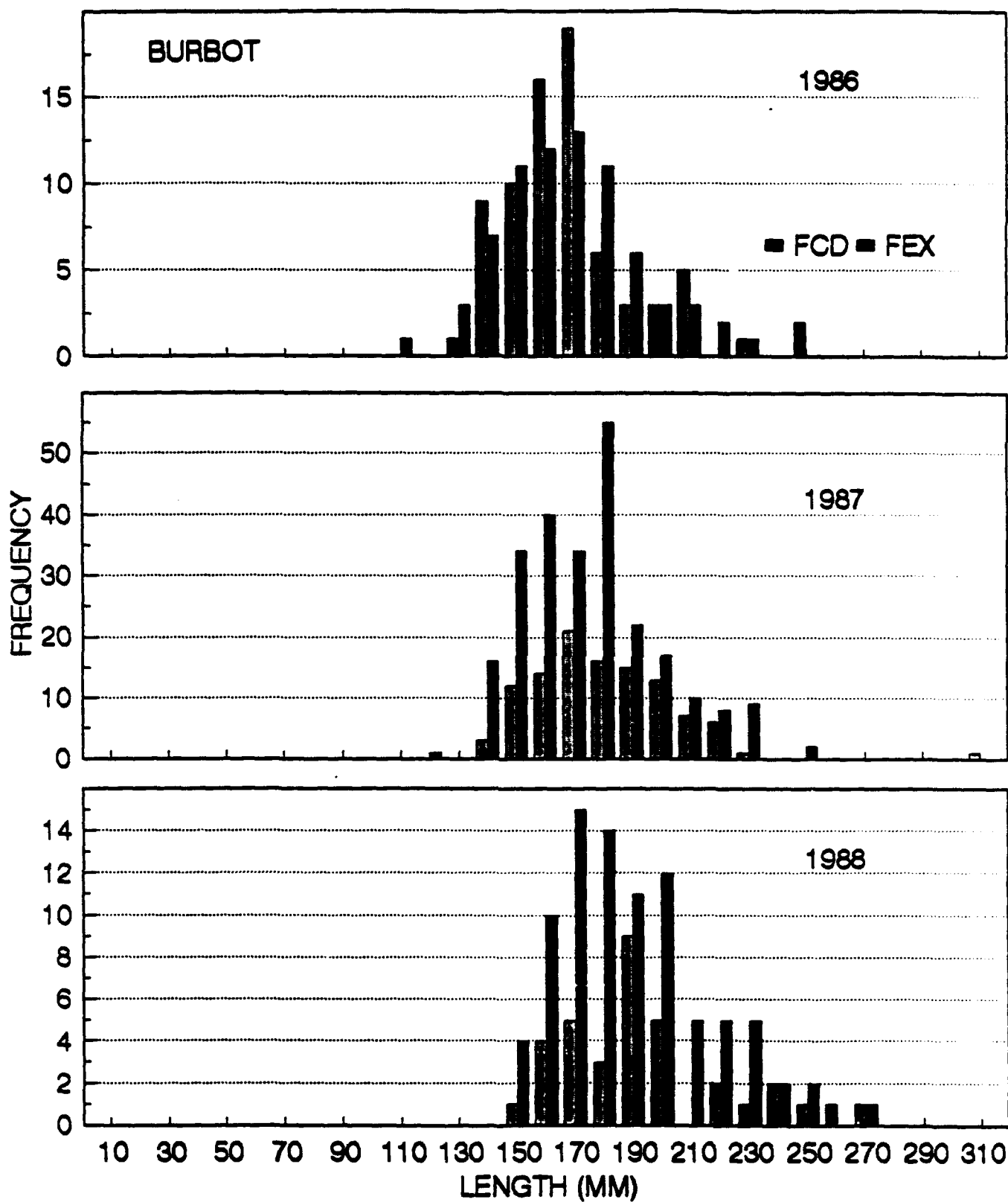


Figure 7.4b. Length frequency distribution of annual catch of burbot at FCD and FEX from 1986 to 1988.

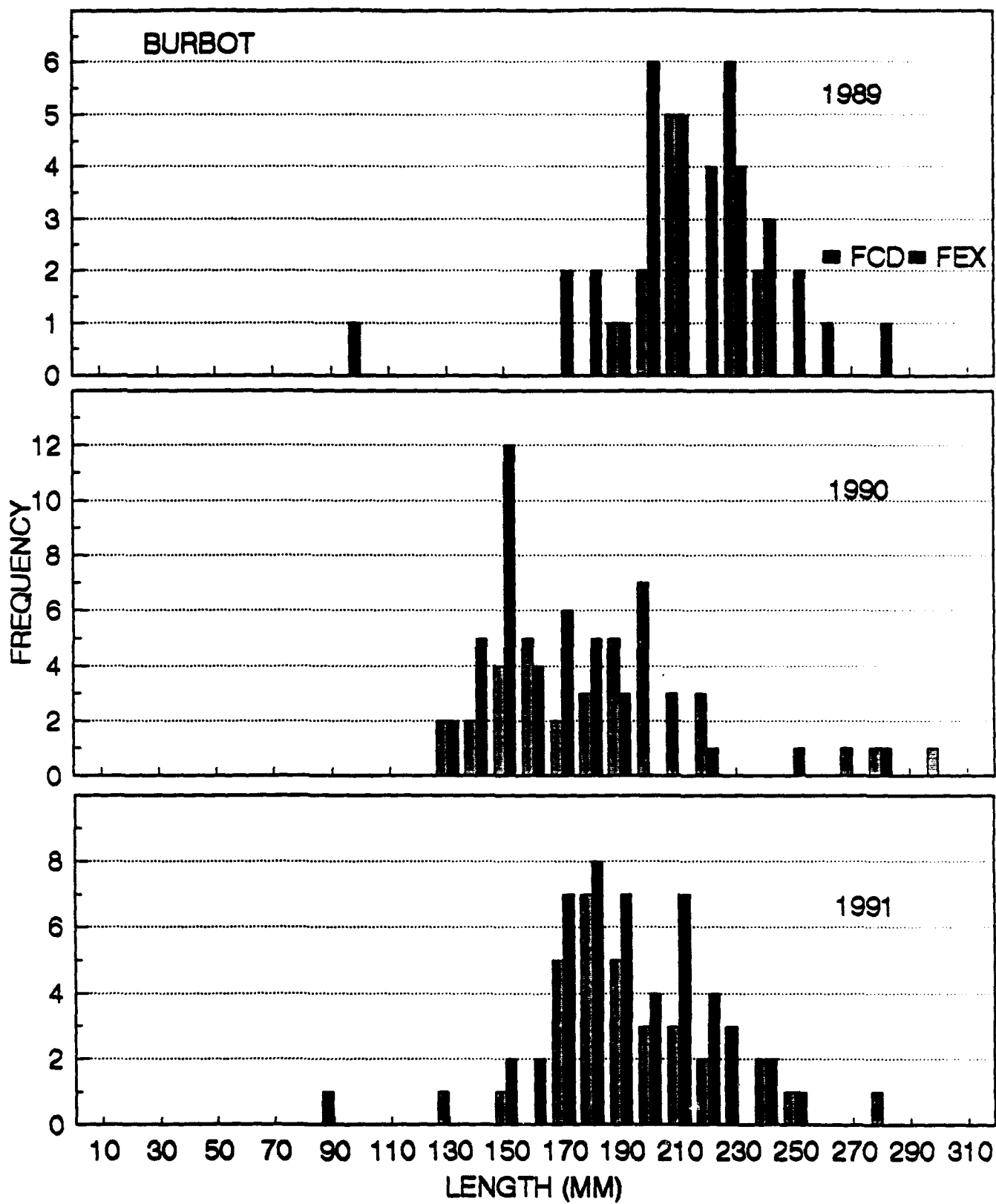


Figure 7.4c. Length frequency distribution of annual catch of burbot at FCD and FEX from 1989 to 1991.

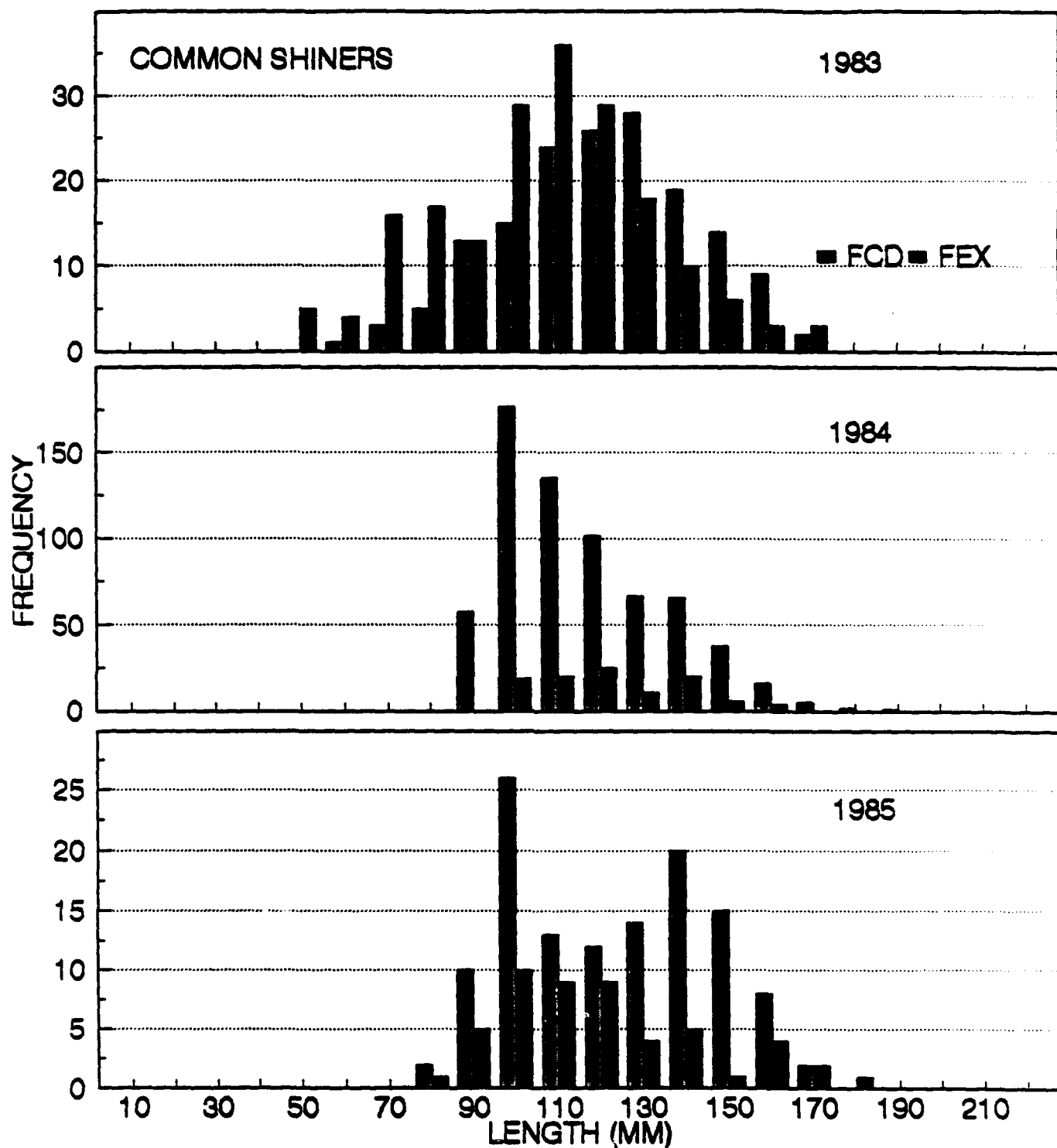


Figure 7.4d. Length frequency distribution of annual catch of common shiners at FCD and FEX from 1983 to 1985.

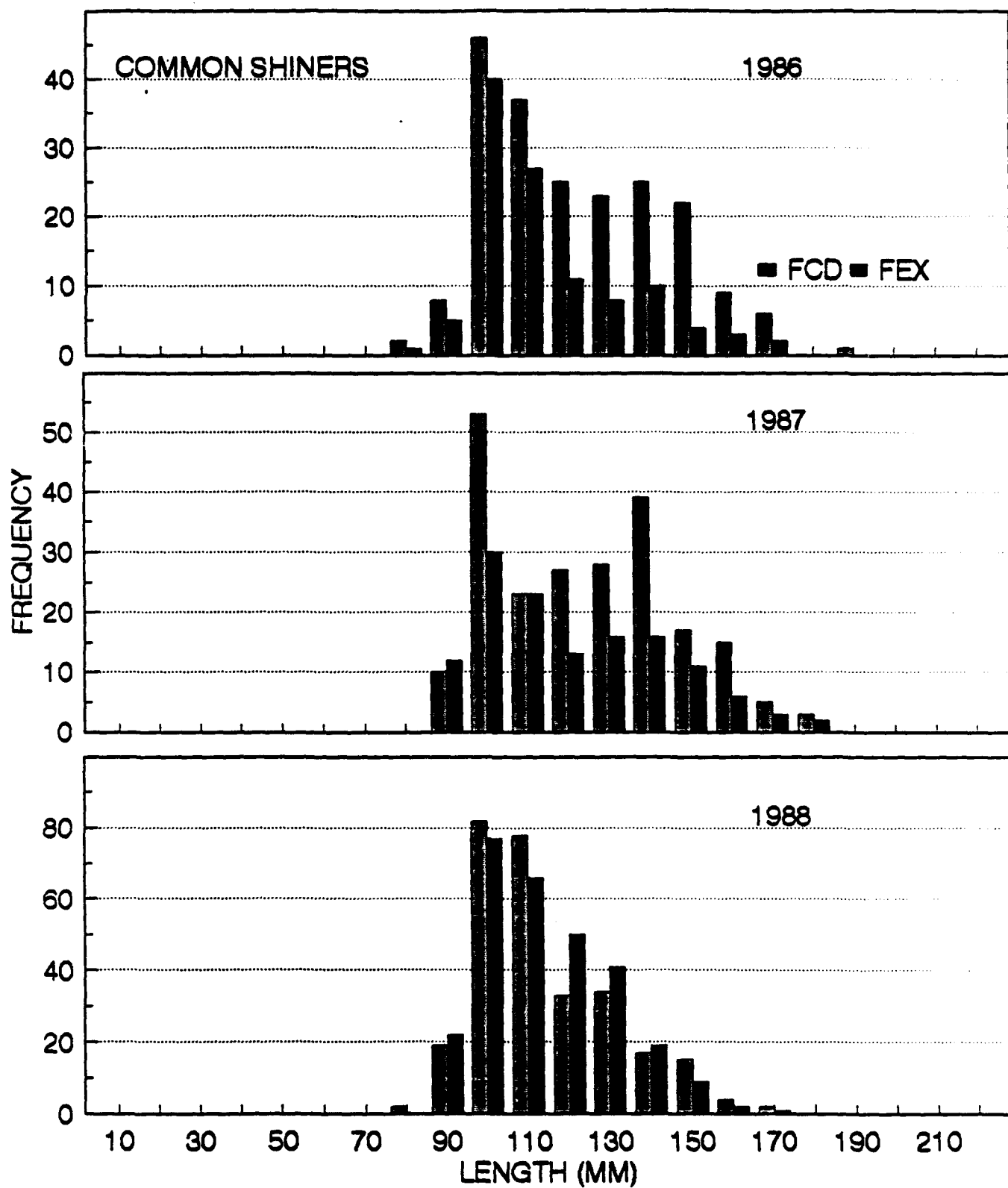


Figure 7.4e. Length frequency distribution of annual catch of common shiners at FCD and FEX from 1986 to 1988.

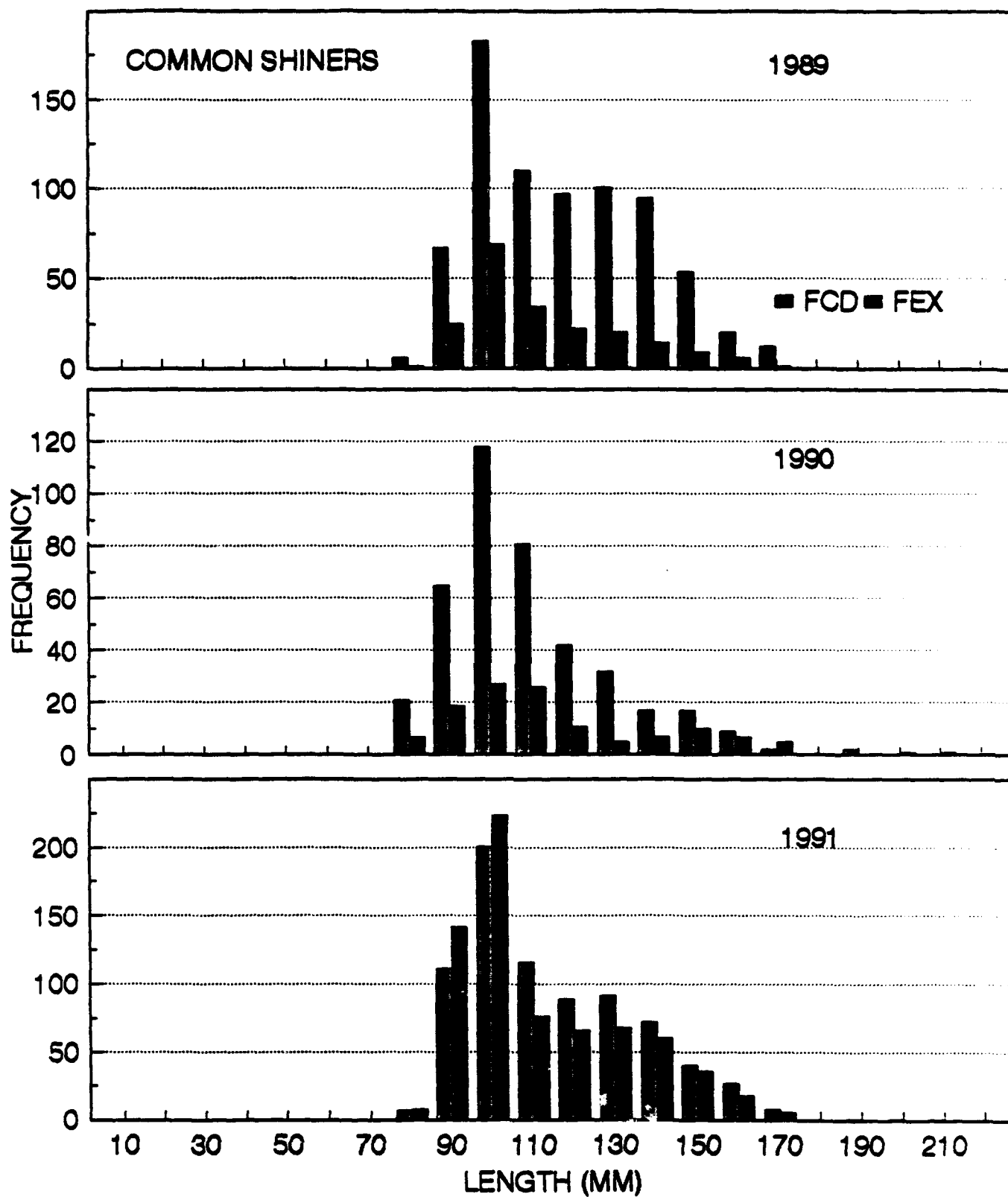


Figure 7.4f. Length frequency distribution of annual catch of common shiner at FCD and FEX from 1989 to 1991.

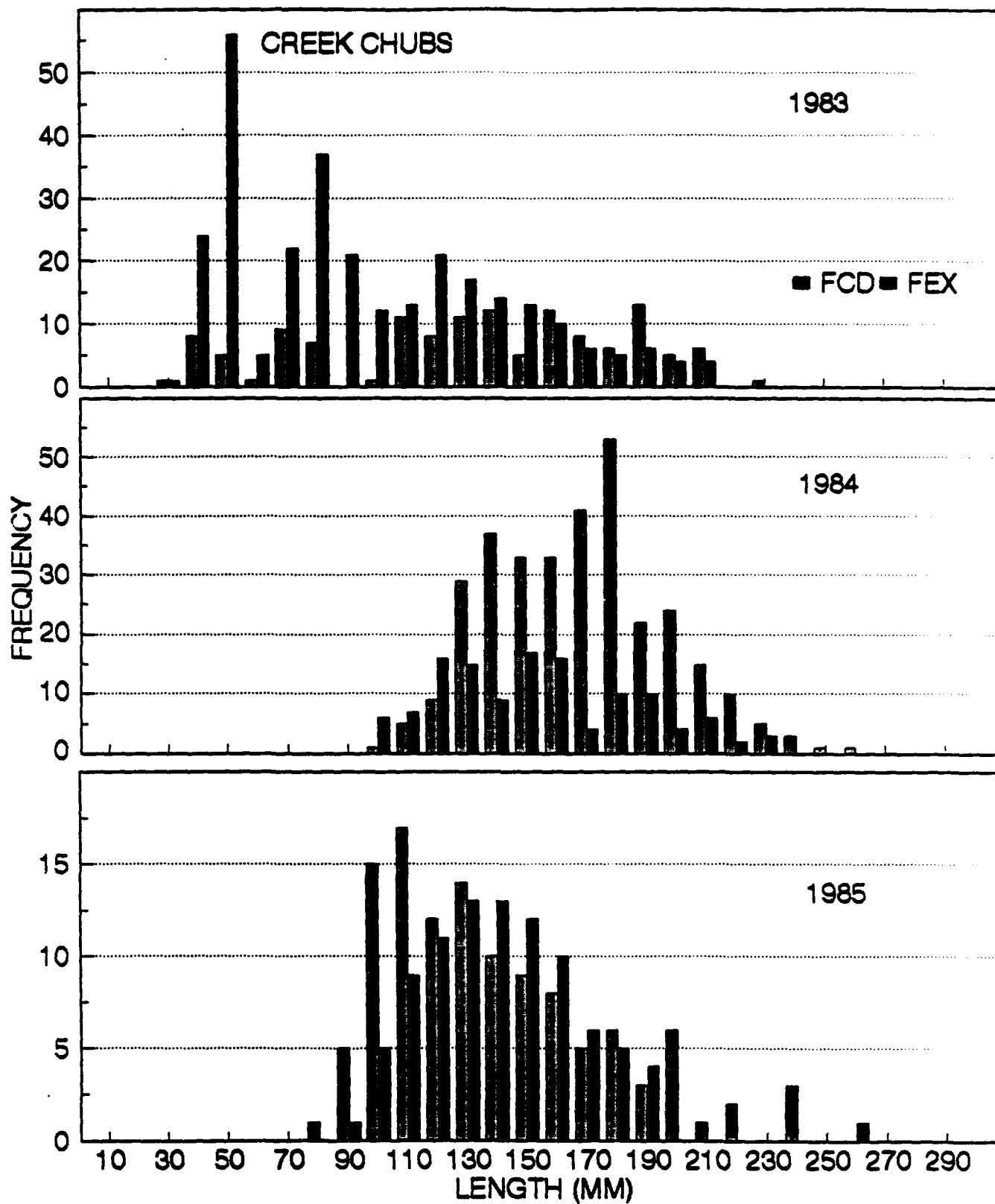


Figure 7.4g. Length frequency distribution of annual catch of creek chubs at FCD and FEX from 1983 to 1985.

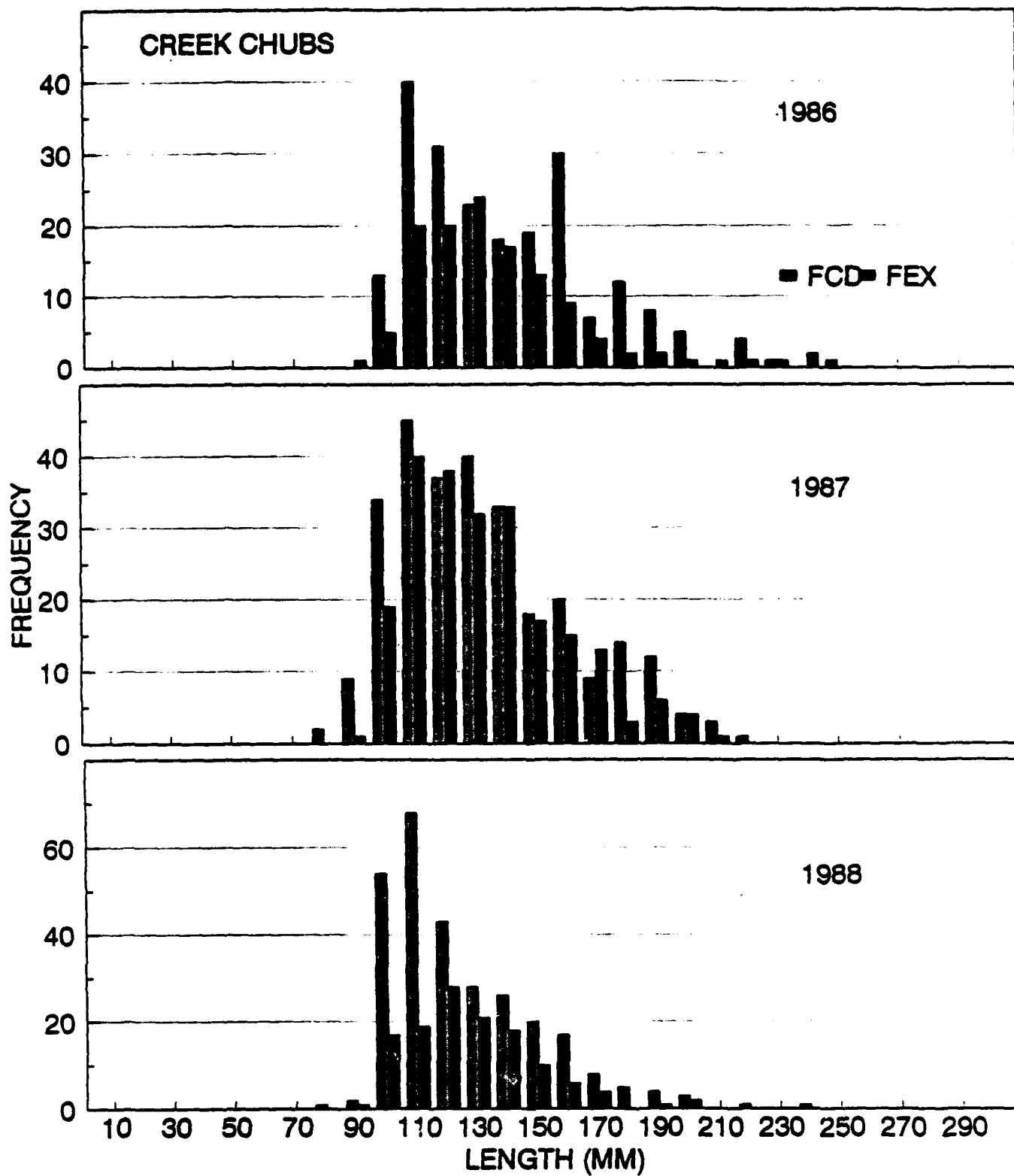


Figure 7.4h. Length frequency distribution of annual catch of creek chubs at FCD and FEX from 1986 to 1988

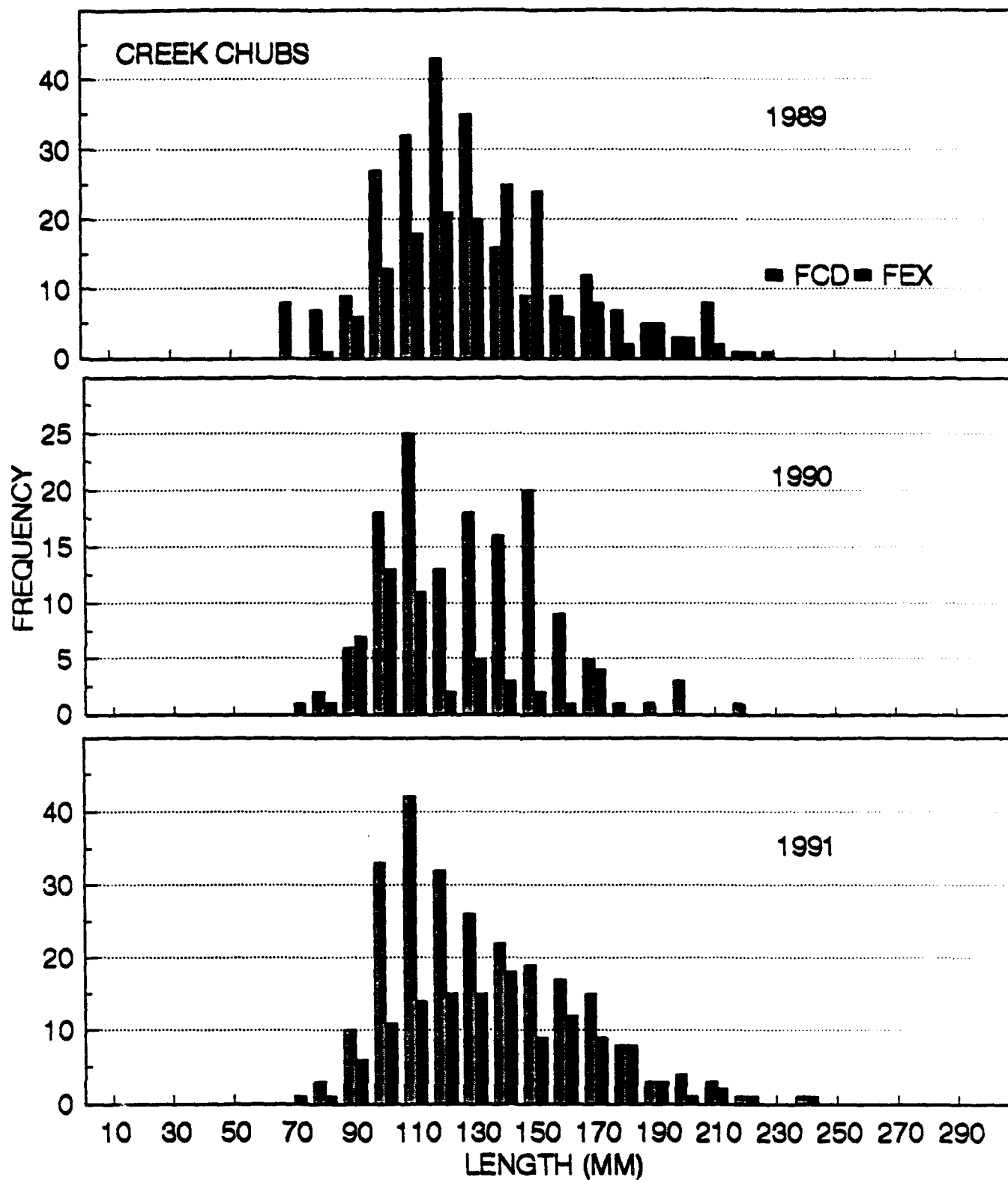


Figure 7.4I. Length frequency distribution of annual catch of creek chubs at FCD and FEX from 1989 to 1991.

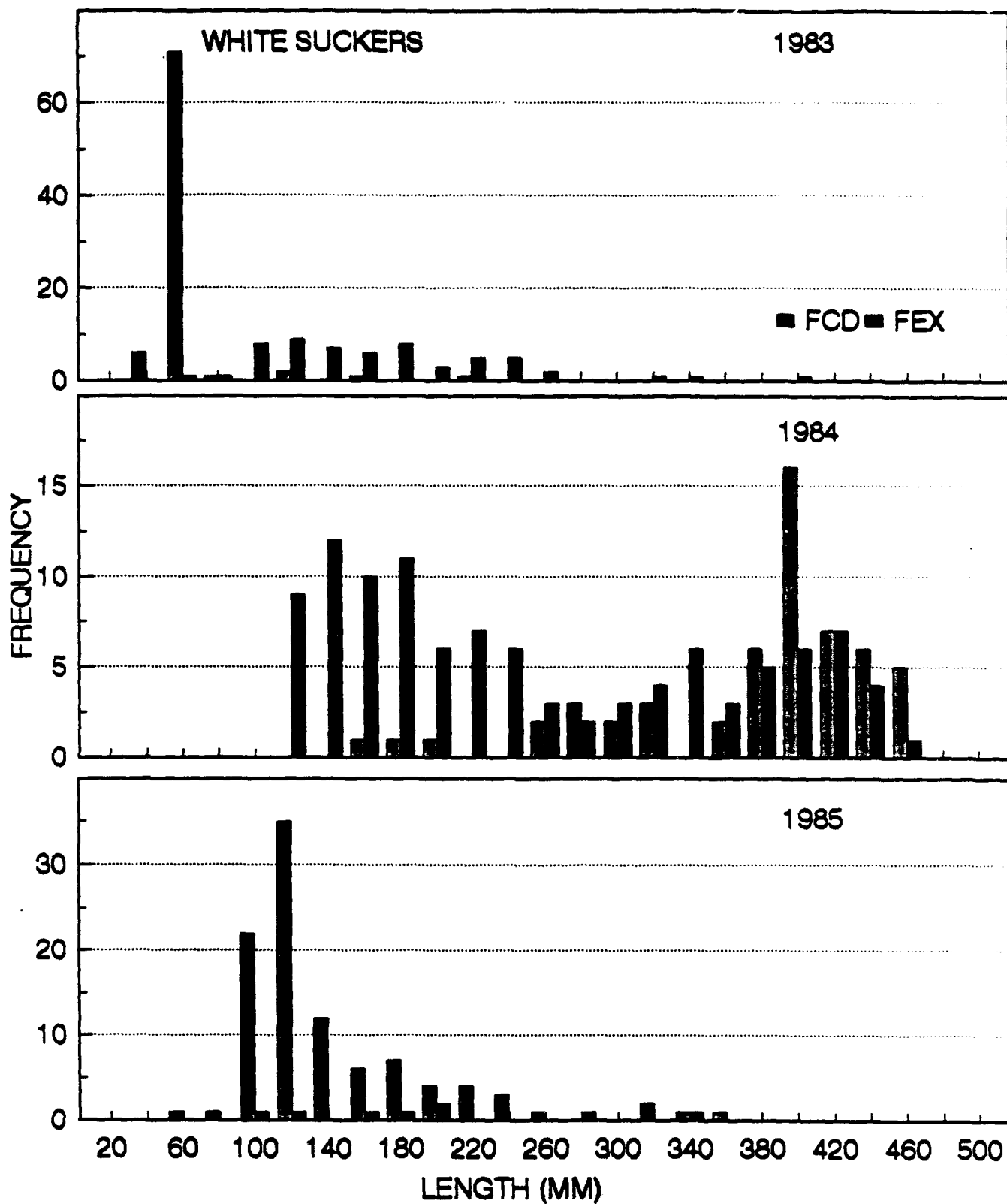


Figure 7.4]. Length frequency distribution of annual catch of white suckers at FCD and FEX from 1983 to 1985.

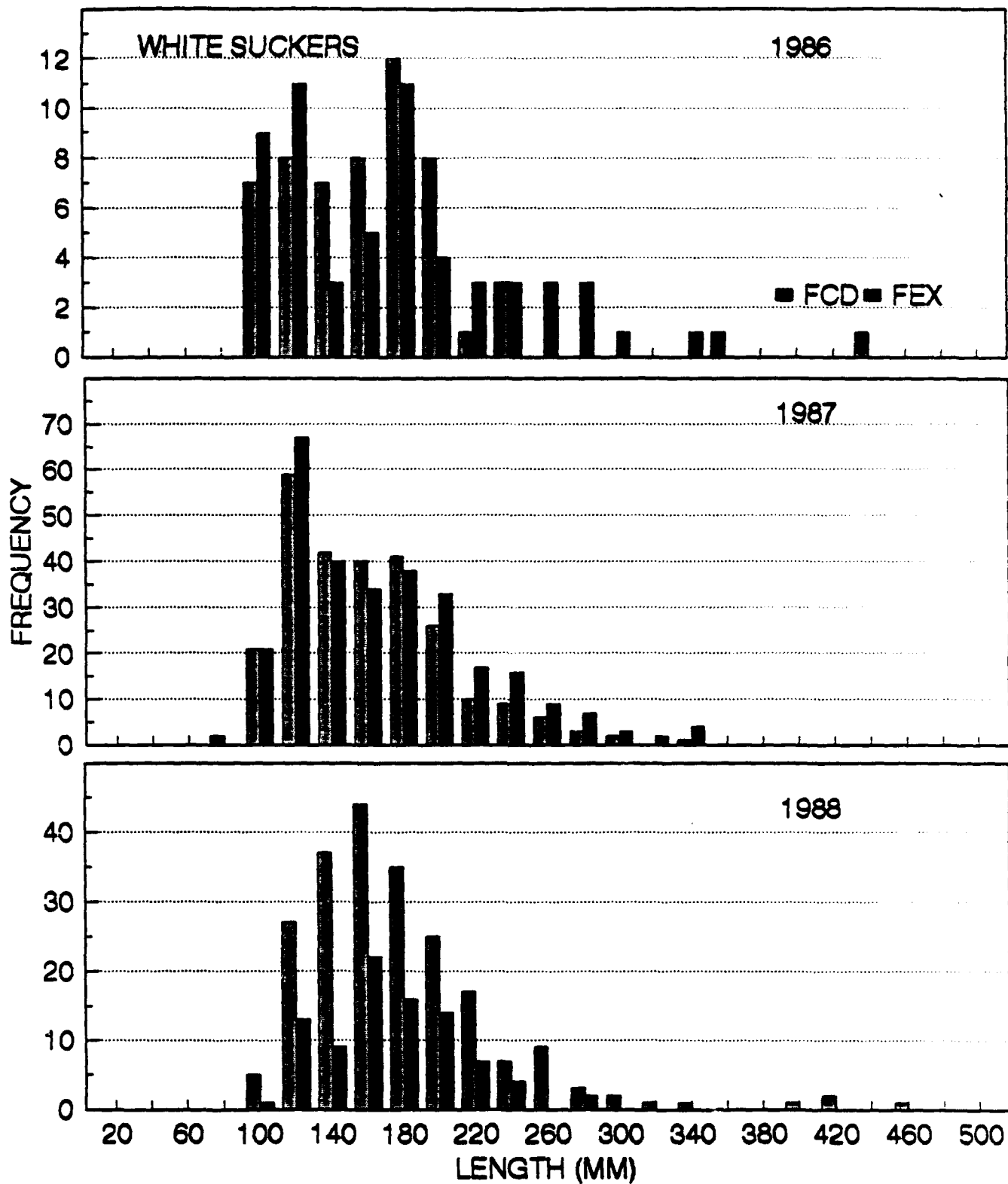


Figure 7.4k. Length frequency distribution of annual catch of white suckers at FCD and FEX from 1986 to 1988.

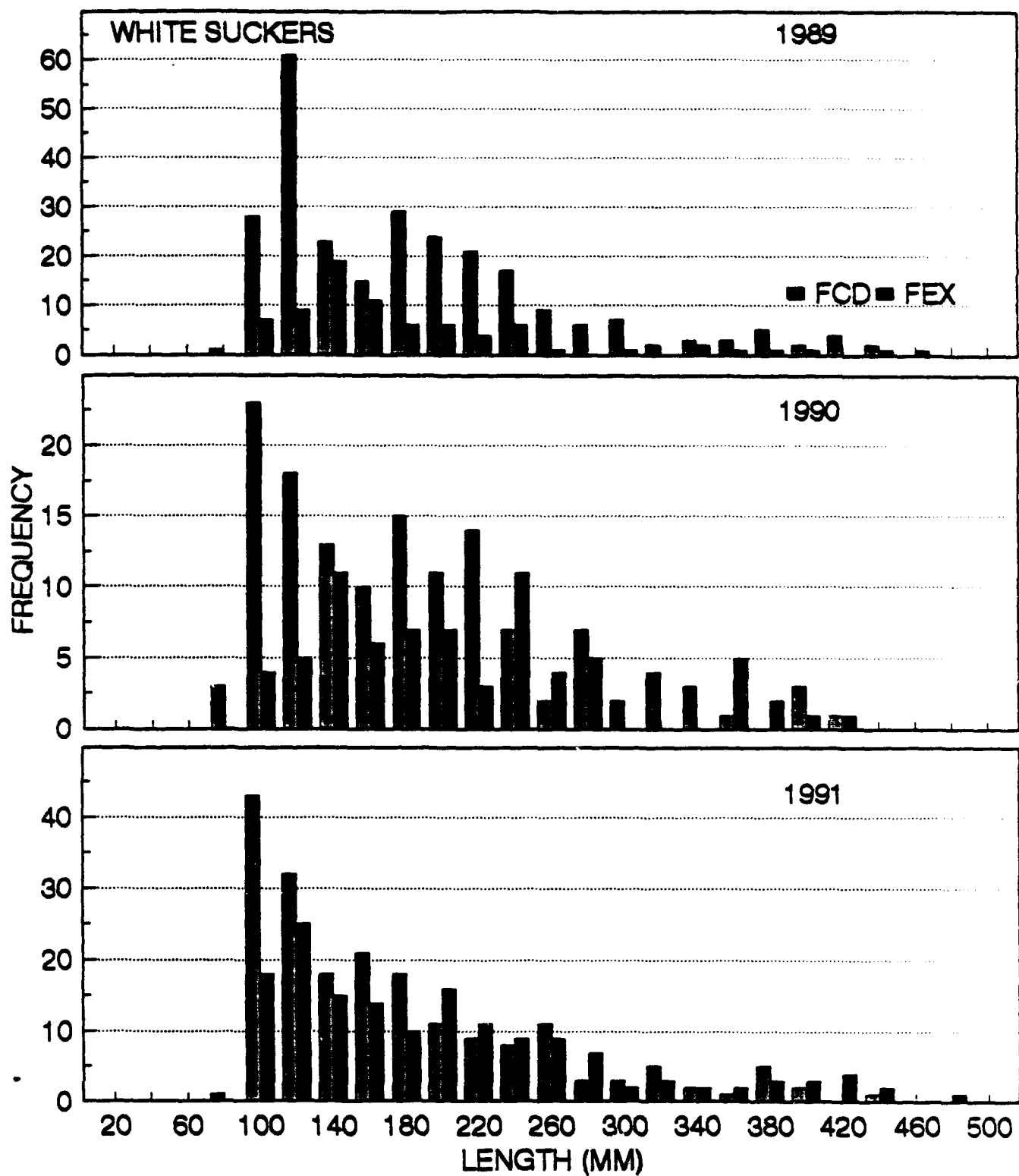


Figure 7.4l. Length frequency distribution of annual catch of white suckers at FCD and FEX from 1989 to 1991.

BT=Brook Trout BUR=Burbot CS=Common Shiner
 CC=Creek Chub WS=White Sucker

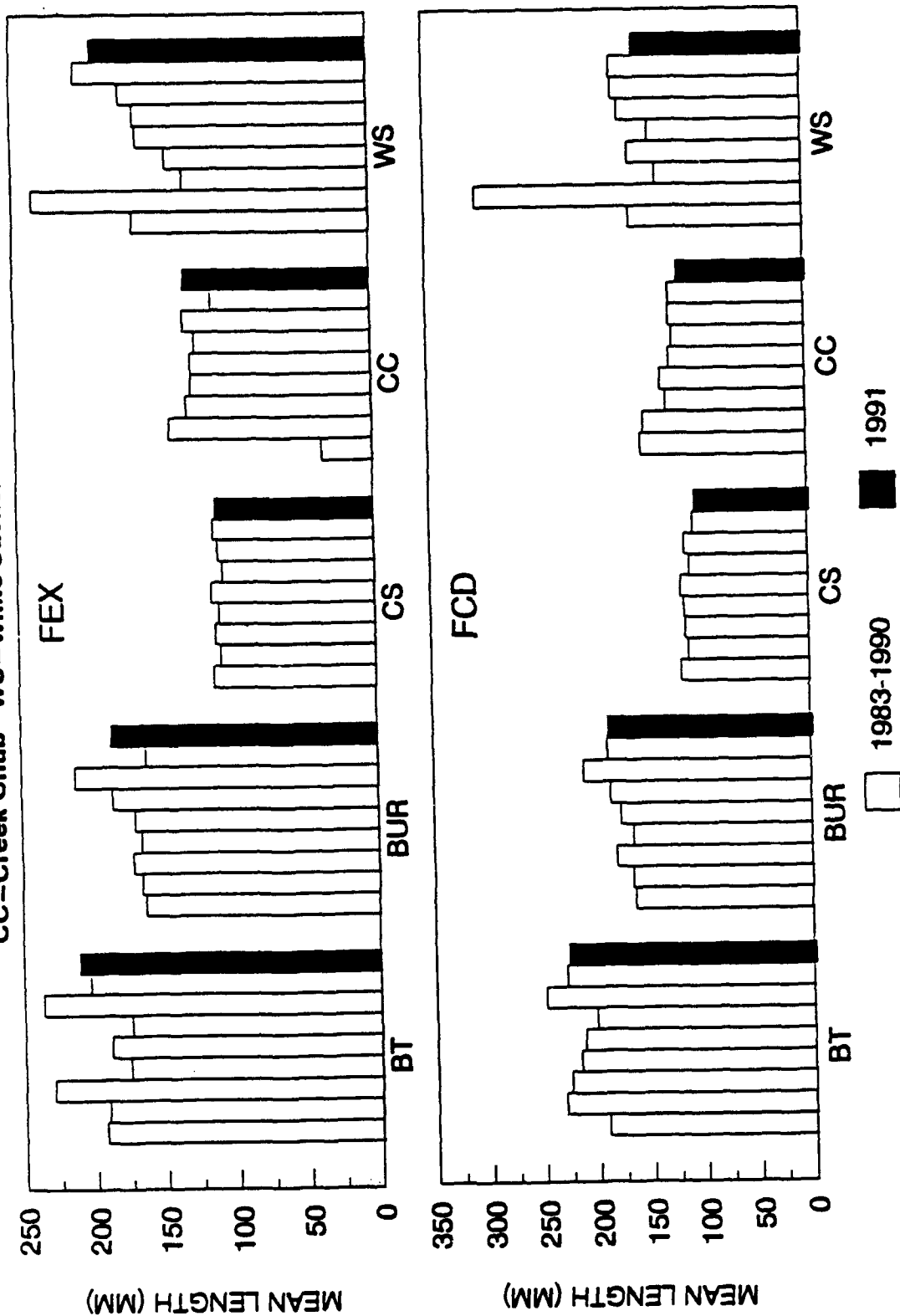


Figure 7.5. Mean length of fish dominating the fyke net catch at FEX and FCD for 1983 through 1991.

increased to the highest (231.5 mm) ever. Brook trout mean lengths in 1990 (203.5 mm) and 1991 (208.0 mm) were above the mean for all years (200.1 mm). Burbot (188.2 mm), creek chub (133.7 mm), and white sucker (190.0 mm) mean lengths in 1991 were above means for all years combined (176.2 mm, 129.0 mm, and 174 mm respectively) while common shiner (107.2 mm) mean length was below the average for all years combined (110.6 mm). Overall changes in mean length have been slight which indicates that the size structure is consistent from year to year within the mobile fish community at FEX.

FCD showed a pattern similar to FEX in that brook trout (231.7 mm) and burbot (189.4 mm) mean lengths were well above the means for all years combined (221.2 mm and 181.2 mm respectively) (Figure 7.5). Common shiners (110.8 mm), creek chubs (127.0 mm) and white suckers (164.5 mm) had mean lengths slightly below their means for all years combined (113.4 mm, 132.9 mm and 176.6 mm respectively).

Brook trout and common shiners were generally larger in mean length at FCD than FEX while burbot, creek chubs and white suckers showed no pattern in mean length between sites. Overall, the two sites continued to be similar in mean length and in trends in mean length. Therefore, ELF effects should be detectable through changes in species size structure.

D. Fish Community Mobility

Common shiners, creek chubs, and white suckers demonstrated site to site movement as shown by the recapture rate at sites other than the marking site (Table 7.9a and b). The total number of nonsalmonids marked at FEX and FCD in 1991 were: burbot 83, common shiners 2056, creek chubs 484, and white suckers 472. Overall recapture percentages in 1991 were about average when compared to previous years (Table 7.9a and b). Site to site movement was observed in 1991 for all species with common shiners (8.8%) and burbot (7.2%) showing the highest recapture percentages. Creek chub and white sucker recapture percentages were typically lower at 3.5% and 2.8% respectively.

Movement across the antenna from FEX to FEN was monitored for 17 net days in June. A total of 20 common shiners, 1 white sucker, and 1 brook trout moved from FEX to FEN during this time. In addition, 12 common shiners, 1 white sucker, 3 brook trout, and 1 longnose dace moved from FCD to FEN. Antenna crossing was also observed through the recapture of fish marked at FCD and FEX at TM and FCU. A total of 2 white suckers, one from FCD and one from FEX, and 1 common shiner from FCD were recaptured at FCU. At TM, 1 creek chub, 1 white sucker and 1 burbot clipped at FEX were recaptured along with 5 common shiners and 1 white sucker

Table 7.9a. Recapture data summary for all dominant species except brook trout from FEX and FCD for 1984 - 1987.

% Recapture by Location							
Species	Total Marked	Number Recaptured	% Recaptured	Marking Site	Upstream 1 Site	Down 1 Site	Up 2 Sites
1984							
Burbot	405	15	3.7	86.6	6.7	6.7	
Common shiner	1085	122	11.3	79.5	11.5	9.0	
Creek chub	700	72	10.3	81.9	12.5	5.6	6.7
White sucker	405	15	3.7	86.6	6.7		
1985							
Burbot	170	22	12.9	86.3	4.5	9.2	3.2
Common shiner	622	63	10.1	77.8	9.5	9.5	
Creek chub	520	28	5.4	82.1	14.3		
White sucker	125	2	1.6	100.0			
1986							
Burbot	218	15	6.9	80.0	13.3	6.7	
Common shiner	612	68	11.1	89.7	7.3	3.0	
Creek chub	535	31	5.6	96.8	3.2		
White sucker	259	12	4.6	75.0	16.7	8.3	
1987							
Burbot	540	45	8.3	95.6	2.2	2.2	
Common shiner	1693	172	10.2	88.4	10.5	1.2	
Creek chub	1816	87	4.8	93.1	3.4	3.4	
White sucker	1530	42	2.7	78.6	9.5	9.5	

Table 7.9b. Recapture data summary for all dominant species except brook trout from FEX and FCD for 1988 and 1991.

Species	% Recapture by Location					
	Total Marked	Number Recaptured	% Recaptured	Marking Site	Upstream 1 site	Down 1 site 2 sites Up
1988						
Burbot	340	11	3.2	81.8	18.2	
Common shiner	1402	75	5.3	88.0	6.7	5.3
Creek chub	2649	96	3.6	90.6	4.2	5.2
White sucker	1113	15	1.3	100.0		
1989						
Burbot	57	4	7.0	100.0		
Common shiner	3348	446	13.1	79.8	7.8	10.8
Creek chub	856	28	3.2	92.9	7.1	
White sucker	542	21	3.9	81.0		19.0
1990						
Burbot	84	5	6.0	100.0		
Common shiner	1354	166	12.3	92.8	4.2	3.0
Creek chub	253	8	3.2	62.5		37.5
White sucker	242	7	2.9	100.0		
1991						
Burbot	83	6	7.2	50.0	33.3	16.7
Common shiner	2056	180	8.8	80.0	14.4	6.7
Creek chub	484	17	3.5	76.5	23.5	
White sucker	472	13	8.8	30.8	38.5	15.4

from FCD.

E. Individual Species Analyses

Growth and condition of fish can be important indicators of a stressor in the fish community. Four species were chosen based on abundance (common shiners, creek chubs, white suckers and brook trout) as indicator species in the community to examine the potential effects of the ELF project on growth and condition. Brook trout data are reported on in element 8.

The age and growth of common shiners, creek chubs, and white suckers has not been completed due to a change in analysis methods. Length frequency distribution analysis has been determined to be a better method for determining age and growth of these species. The length frequency distributions for these species are given in Figure 7.4(d-1).

Fish condition factors for common shiners, creek chubs and white suckers were calculated using relative weight (Wr) condition analysis as described in Wege and Anderson (1978). Standard weight (Ws) formulas were calculated from 3 literature populations for common shiners, 5 literature populations for creek chubs and 13 literature populations for white suckers using the 50% percentile method outlined in Wege and Anderson (1978). Individual weights were then compared to the standard weights and given a Wr value based on the formula: $Wr = \text{Fish weight} / Ws * 100$. Mean values for 25 mm length groups for common shiners and creek chubs, and 50 mm white sucker were calculated for an unweighted analysis of the data. Data from FEX and FCD were pooled because of the high amount of mobility seen in the Ford River.

The Ws formulas for common shiners, creek chubs and white suckers are as follows:

Common shiners	$\log wt = -5.3907 + 3.1704 * \log tl$	(r=.999)
Creek chubs	$\log wt = -4.8488 + 2.9295 * \log tl$	(r=.998)
White suckers	$\log wt = -4.9820 + 3.0073 * \log tl$	(r=.98)

where,

wt = weight
tl = total length

The condition factor (Wr value) for white suckers was below the species means from populations reported in the literature possibly reflecting the highly variable abiotic conditions in the Ford River (Figure 7.6). Common shiner and creek chub Wr values in 1991 were slightly below the species mean from populations reported in the literature. Creek chubs declined in condition from above the species

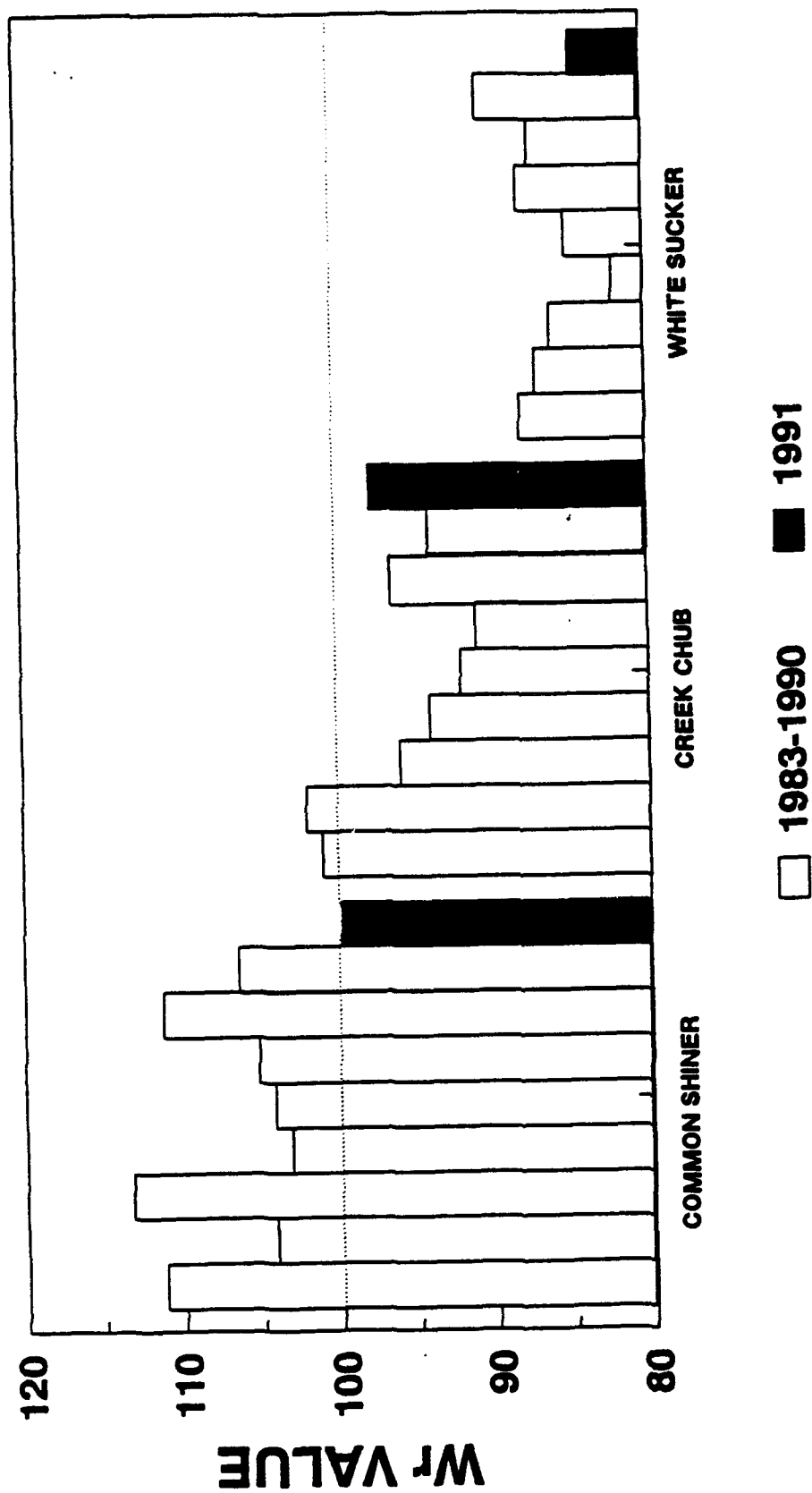


Figure 7.6. Yearly unweighted relative weight values for common shiners, creek chubs and white suckers in the Ford River. Dotted line at 100 indicates a condition equal to the average calculated from several populations in the literature.

mean in 1984 and 1985 to approximately 5 - 10% below the species mean in 1987 through 1991. White sucker condition was 10 - 15% below the species mean in all years. Common shiner condition decreased from 6.5% above the species mean in 1990 to 0.1% below the mean in 1991. This is the first year that shiners exhibited a condition that was below the literature mean. This may be due to density dependent factors acting on this species.

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Element 8 - Brook Trout Population Characteristics and Movement

Changes from workplan: Data analysis design structured in this manner; pre-operational years (1983-1985), transitional years (1986-1989), and post-operational years (1990-1991). The primary analysis presented in this report compare pre-operational years with transitional and post-operational years.

Objectives

The overall goal of this element is to examine the effects of the Navy's ELF project on brook trout (Salvelinus fontinalis) populations; an important sportfish to local residents. Earlier we showed that brook trout in the Ford River were highly mobile and are excluded from portions of the mainstream when water temperatures exceed 16 C. Any impediments to this migration pattern could affect growth and survival as trout are less efficient bioenergetically in water above 16 C (Graham, 1949). The specific objectives of this element are to determine: 1) The seasonal pattern and magnitude of brook trout movement under the ELF antenna; 2) The proximate cause(s) for these movements; 3) The rate of brook trout movement under the ELF antenna; 4) The relationship between length frequency distributions from fyke net catches and DeLury and Peterson population estimates; and 5) Population characteristics (age, growth and condition) of Ford River brook trout. By accomplishing these objectives, we will be able to evaluate if the ELF system has an impact on the population characteristics and movement of Ford River brook trout.

Materials and Methods

The sites and gear used in this element were previously described in Element 7. All brook trout were removed on a daily basis from the fyke nets or weir traps and anesthetized with MS-222 at a 500 mg/l dosage as recommended by Meister and Ritzi (1958), and Schoettger and Julin (1967) to reduce handling stress. All brook trout were then enumerated, measured for total length and weighed. Scale samples were taken from each fish for age and backcalculated growth determination in the laboratory. All fish were given a site specific fin clip. In 1983-1985, fish longer than 135 mm were tagged using streamer or disk tags applied posterior to the dorsal fin. Due to a high incidence of infection in these years, strap tags were applied to the adipose fin and the operculum in 1986 and 1987 respectively. Tagged fish recaptured at the site of

initial tagging and angler reports during these two years suggested poor tag retention. In 1988 brook trout were fin clipped with a site specific mark only. In 1989 through 1991 fish greater than 140 mm were tagged using Visible Implant (V.I.) Tags manufactured by Northwest Marine Technologies, while fish less than 140 mm were marked with a site specific fin clip only. The V. I. Tag is inserted into clear, cartilaginous tissue posterior to the eye. Prior research has shown greater than 90% retention, less than 2% mortality, and no infection on rainbow trout in the laboratory (Stan Moberly, personal communication). After tagging, all fish were released upstream or downstream from the site in their original direction of travel.

The effect of discharge and temperature on brook trout movement at FEX and FCD were evaluated using ambient monitoring data collected by Dr. Tom Burton and staff (see Element 1). Physical data (discharge and temperature) at FCU and TM were collected by the fisheries staff from 1984-1991. Discharge was calculated from a calibrated staff gauge at both FCU and TM on a daily basis. Temperature data was collected continuously using a calibrated max-min thermometer at TM and FCU. In addition, Ryan tempmentors and/or thermographs were deployed in 1988 through 1991 at these two sites so that temperature could be monitored on a continuous basis.

Population estimates and size distributions were obtained using either a 250 volt electrofishing boat type unit during normal to high flows or a 250 volt Coffelt backpack unit during low flows. Electrofishing site locations (200 m in length) were established between one and two miles from net sites or ambient monitoring stations. In 1987 and 1988 a DeLury removal estimate (Ricker 1975) was obtained at each site during premovement (May), postmovement (late July - early August) and fall (mid September) periods. Three removal runs were made at each site during the sampling day. Fish captured were measured for total length and held in a holding cage placed in the stream until all three passes were completed. Fish were then released. In 1989 estimates were taken monthly from May 20 to October 23 at the same sites using the Peterson mark and recapture technique (Ricker 1975). Sites in 1989 were extended to 300 meters. Brook trout captured on the marking run were measured for total length, weighed and marked with a partial fin clip. Fish greater than 140 mm were marked using V. I. Tags. Recapture runs were made on the next day during all sampling periods. Unmarked fish captured on the recapture run were given a site specific fin clip and if larger than 140 mm, tagged with a V. I. Tag. In 1990, Peterson estimates were taken during the pre- and post-movement period only using the same methodology described for 1989.

Brook trout age and growth determination were done using

the body-scale relationship technique described in Smale and Taylor (1987). Backcalculations were made using the linear technique described in Bagnenal and Tesch (1978). Scales were projected onto a Summagraphics digitizing pad using a Ken-A-Vision Microprojector scope. The focus, subsequent annuli and the outside edge of each scale were digitized and recorded on a IBM pc for determination of backcalculated length at age.

Results and Discussion

A. Marking Statistics

Numbers of fish tagged at FEX and FCD declined from a high of 314 in 1984 to 126 in 1985 and 82 in 1986 reflecting a decline in the brook trout population. Numbers of fish tagged increased to 170 fish in 1987 and dropped slightly to 142 fish in 1988 and 134 in 1989. Only 74 fish were tagged in 1990 which is below the average (mean = 161) for all years combined. The number of fish marked at FEX and FCD in 1991 jumped back to 244 reflecting favorable environmental conditions over the last 2 years. The between site recapture rate was 18.2% and 12.7% in 1984 and 1985 respectively, 0% in 1986 and less than 1% in 1987 and 1988. The recapture percentage increased to 6.7% in 1989 and to 9.7% in 1990 at FEX and FCD. Recapture percentages in 1991 were the highest ever at 34.2% (Table 8.1). Observed handling and tagging mortality averaged 6.2% from 1984 to 1987. No tagging mortality was observed in 1988 and only 2.2% was seen in 1989. Tagging mortality in 1990 and 1991 was 1.2% and 4.1% respectively (Table 8.1). The percentage of angler returns declined throughout the study from 12.1% in 1984 to 3% in 1985 and 0% in 1986-1989. Anglers returned only 1.2% of tagged fish in 1990 and 2.1% in 1991 (Table 8.1). This may reflect a decrease in the total number of fish harvested in the Ford during this time period, however, we have no quantitative data on angling pressure.

B. Brook Trout Catch Patterns

Brook trout catches peaked in late May to early July depending on weather patterns during the year. Summer catches then dropped to < 1 fish/day and this condition persisted through late August to early September. At this time, daily catch again increased due to spawning activity. Since movement patterns were similar at all sites, data will be presented from FCD to depict between year differences (Figures 8.1 a-d). In 1984 the mean daily catch began to peak during the first week of June and was at its maximum during that week (15.8 fish/day). These high catch patterns continued for three weeks and then dropped to less than 1

Table 8.1. Brook trout marking and recapture summary for FEX and FCD for 1984 - 1991.

		FEX	FCD
1984	Number Tagged	71	243
	Number Fin Clipped	48	37
	Percent Tag Recapture	18.2%	
	Estimated Tagging Mortality	5.7%	
	Percent Angler Recapture	12.1%	
1985	Number Tagged	45	81
	Number Fin Clipped	38	53
	Percent Tag Recapture	12.7%	
	Estimated Tagging Mortality	8.7%	
	Percent Angler Recapture	3.0%	
1986	Number Tagged	15	40
	Number Branded	19	8
	Number Clipped	58	32
	Percent Tag Recapture	0.0%	
	Estimated Tagging Mortality	3.4%	
	Percent Angler Recapture	3.0%	
1987	Number Tagged	97	73
	Number Clipped	127	41
	Percent Tag Recapture	0.1%	
	Estimated Handling Mortality	7.1%	
	Percent Angler Recapture	0.6%	
1988	Number tagged	0	0
	Number Clipped	57	85
	Percent Tag Recapture	0.0%	
	Estimated Handling Mortality	0.0%	
	Percent Angler Recapture	0.0%	
1989	Number Tagged	49	86
	Number Clipped	12	11
	Percent Tag Recapture	6.7%	
	Estimated Handling Mortality	2.2%	
	Percent Angler Mortality	0.0%	
1990	Number Tagged	46	28
	Number Clipped	12	5
	Percent Tag Recapture	9.7%	
	Estimated Handling Mortality	1.2%	
	Percent Angler Recapture	1.2%	

Table 8.1.(continued)

1991	Number Tagged	78	109
	Number Clipped	36	21
	Percent Tag Recapture	74.2%	
	Estimated Handling Mortality	4.1%	
	Percent Angler Recapture	2.1%	

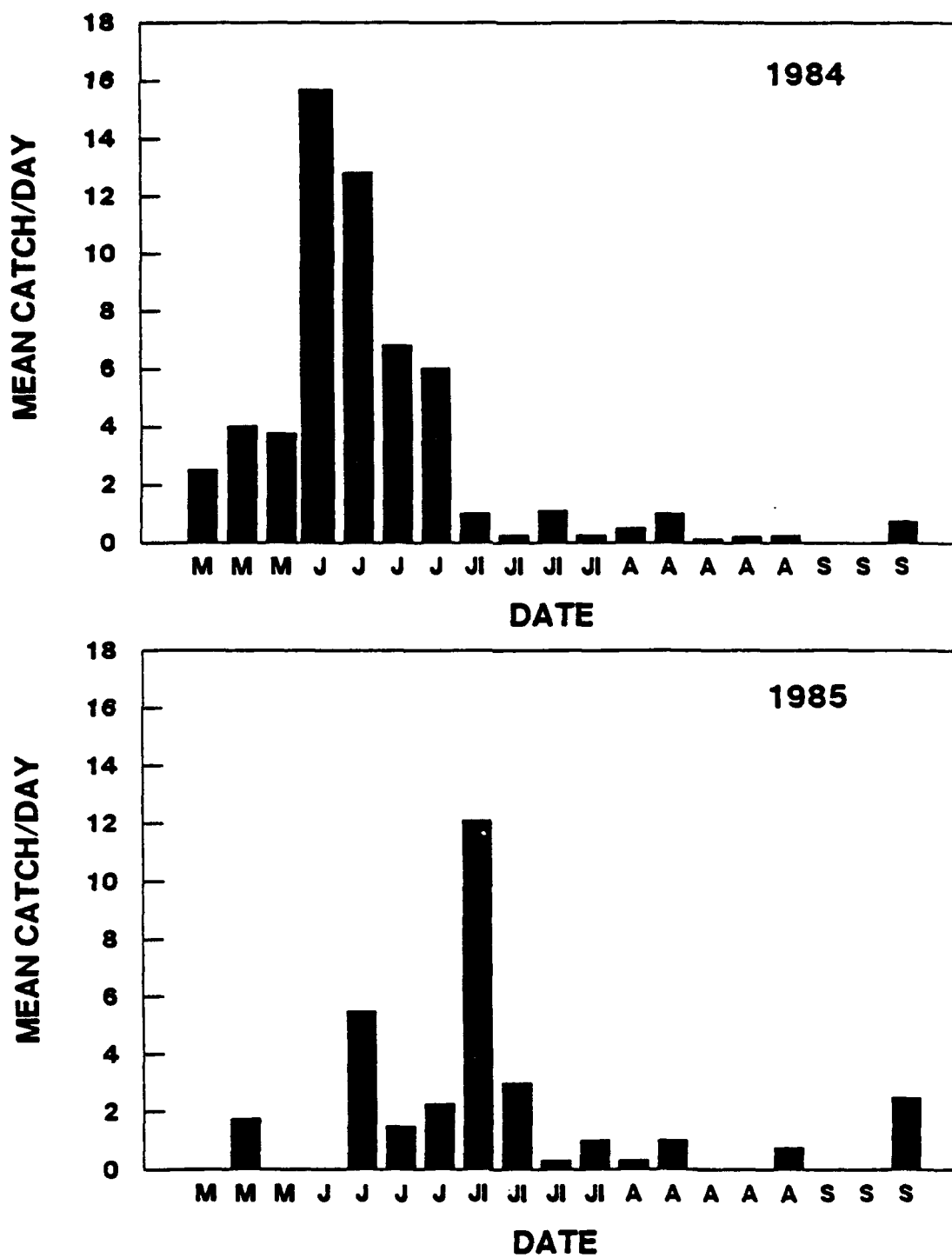


Figure 8.1a. Mean daily catch of brook trout plotted on a weekly basis at FCD from 1984 and 1985.

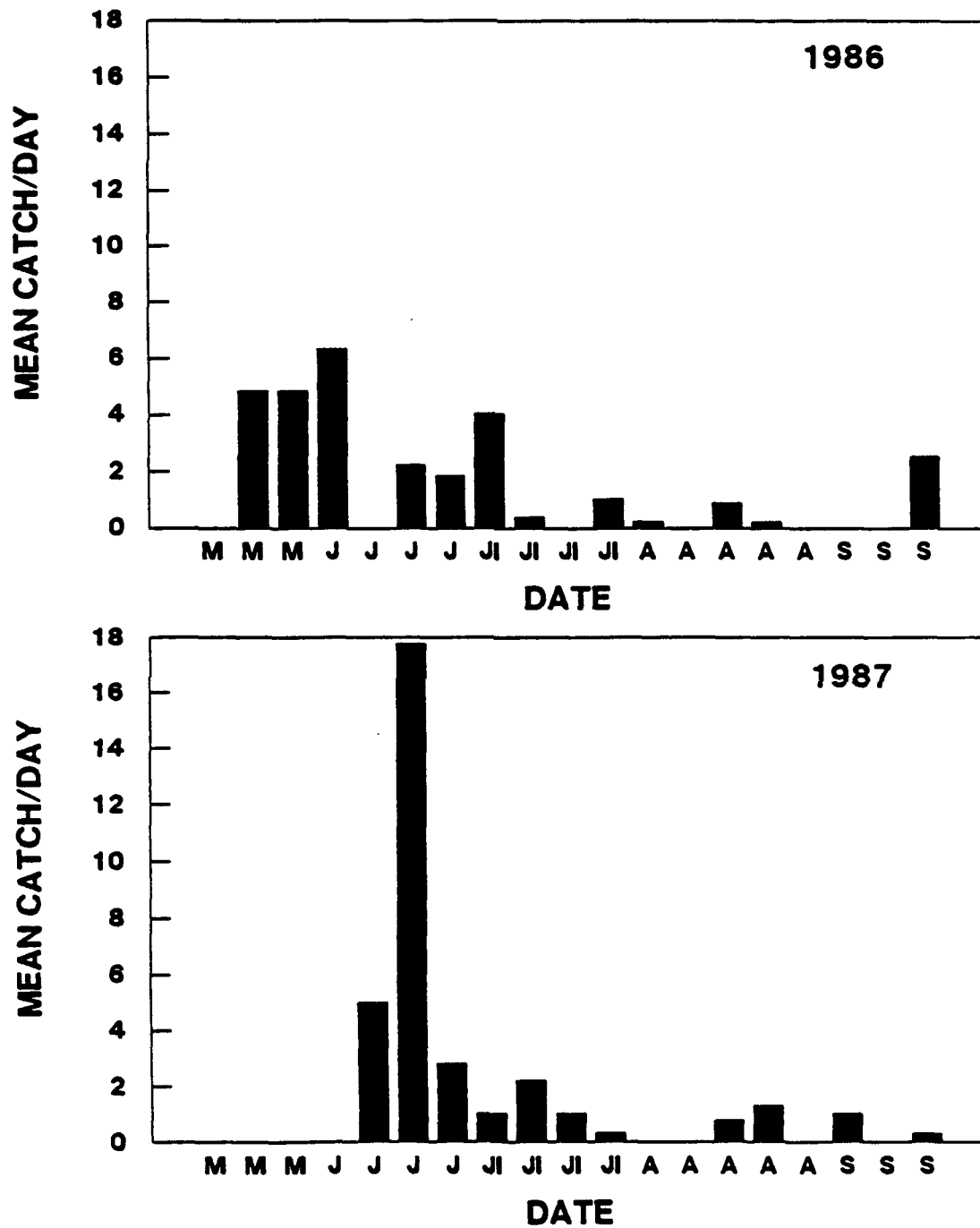


Figure 8.1b. Mean daily catch of brook trout plotted on a weekly basis at FCD from 1986 and 1987.

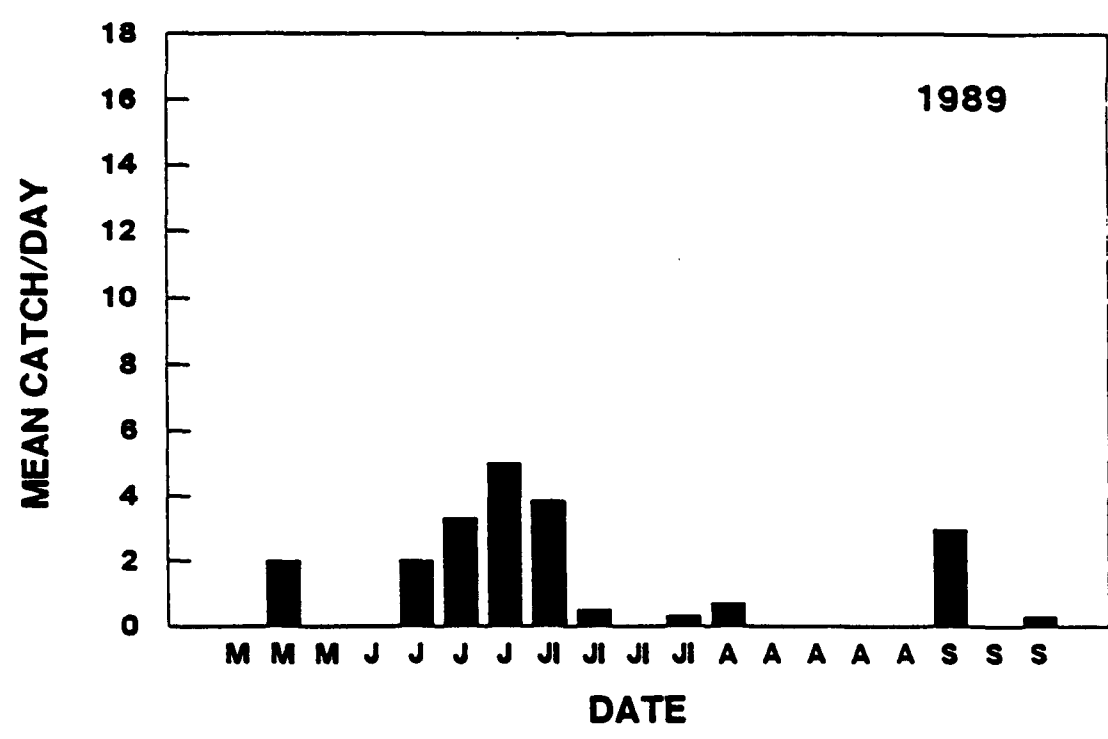
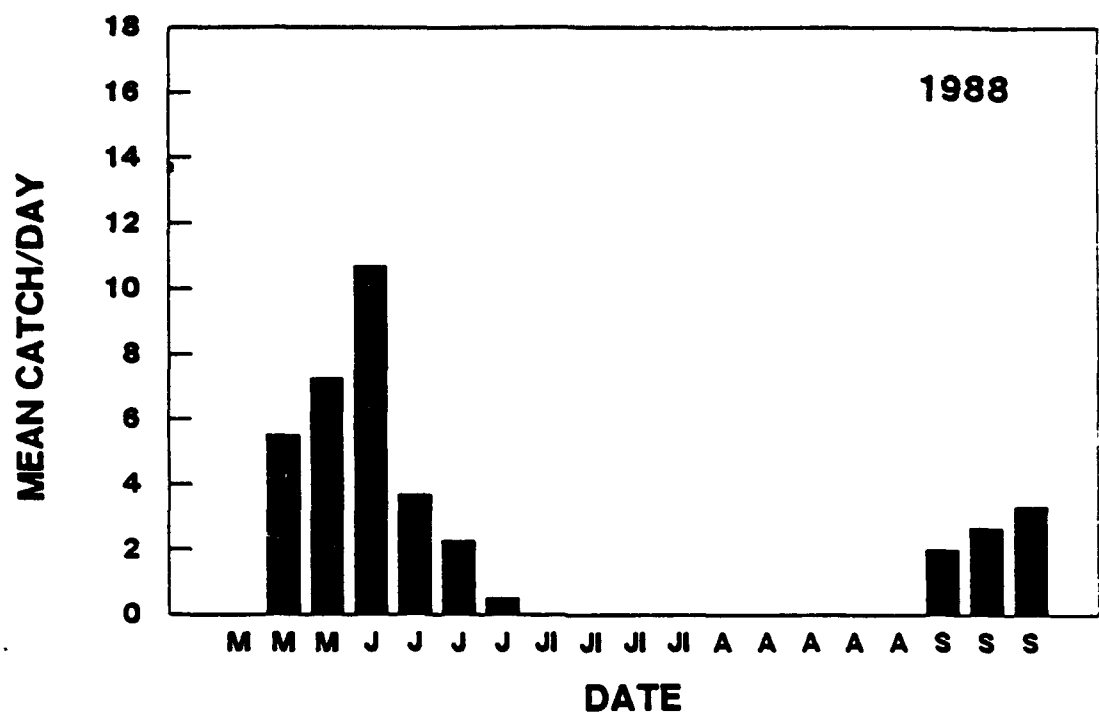


Figure 8.1c. Mean daily catch of brook trout plotted on a weekly basis at FCD from 1983 and 1989.

fish/day during July through September. A similar pattern was seen in 1985 although the peak run was delayed one month beginning the first week of July when 11.7 brook trout per day were collected. This continued for a one week period after which catch rates decreased rapidly to < 1 fish per day. Catch rates in 1986 began increasing during the second week of May and peaked earlier than in previous years, during the last week of May and the first week of June (6.4 fish/day). Results in 1987 were similar in distribution to 1984 catch rates although the peak occurred during the third week of June at 17.8 fish/day and lasted for only one week. In 1988 catch rates started to increase the last two weeks of May and peaked at 10.5 fish/day during the first week of June, similar to 1984. The 1989 catch peaked during the last week of June (5.1 fish/day) and lasted for a one week period. The 1990 catch began to increase during the last week of June and then peaked in early July. The brook trout catch in 1991 increased from late May until mid June and rates stayed high until mid July.

Movement in the upstream direction dominated in all years at all sites making up over 90% of the brook trout catch, however, the intensity and timing varied from year to year. If the ELF operation interferes with the migratory pattern of brook trout, we should be able to observe disoriented behavior through decreased upstream movement or random movement patterns at the FEX site.

Brook trout movements were directed from FEX and FCD upstream toward a coldwater tributary, Two Mile Creek. Eighteen brook trout marked at FEX were recaptured at TM during the pre-operational period from 1984-1985 (Table 8.2). During the transitional period (1986-1989), three trout were observed to have made this movement while 23 trout made this movement during post-operational years (1990-1991). Pre-operational movement from FCD to FEX was observed for ten brook trout. Three fish made this movement in the transitional period and eight during post-operational years. Movement from FCD to TM was observed for forty-five brook trout from 1984-1985. One fish moved this distance during the transitional period. Thirty-three fish were observed making this movement during the post-operational years (1990 and 1991), however, all this movement occurred in 1991. Movement from site to site was observed to be significantly greater for fish above 190 mm than those below 190 mm. Only six clipped fish under 190 mm were captured at TM in 1984 and no clipped fish under 190 mm were collected at TM from 1985 through 1990. In addition, only three fish were observed moving from Two Mile Creek to FCD or FEX from 1984 through 1991 during the summer sampling period. Evidence of fall or early spring downstream movement was supported by the movement of three marked fish from the TM site in 1984 to FCD in 1985. One fish marked in 1990 from

Table 8.2. Brook trout site to site movement rate summary for 1984 through 1991.

Year	Recapture Type	Site Marked to Site Recaptured		Distance (km)	N	Mean Rate (km/day \pm 1SD)	Mode (km/day)
1984	Recaptured Fish	FEX- TM		12.7	11	1.4 \pm 0.9	1.2
		FCD- TM		26.8	39	2.9 \pm 1.7	2.5
		FCD-FEX		14.1	7	2.7 \pm 1.6	2.0
1985	Recaptured Fish	FEX- TM		12.7	7	1.6 \pm 0.9	1.1
		FCD- TM		26.8	6	5.0 \pm 3.2	4.2
		FCD-FEX		14.1	3	1.2 \pm 0.3	1.3
1986	No Recaptures						
1987	Recaptured Fish	FEX- TM		12.7	1	1.8	1.8
1988	Recaptured Fish	FCD-FEX		14.1	2	2.3 \pm 0.7	1.0
1989	Recaptured Fish	FEX-TM		12.7	2	0.7	4.5
		FCD-TM		26.8	1	4.5	2.8
		FCD-FEX		14.1	1	2.8	
		FEX-FCD		14.1	2	1.9	6.7
		TM-FCD		26.8	1	6.7	
1990	Recaptured Fish	FCD-FEX		14.1	2	2.2 \pm 1.87	2.2
1991	Recaptured Fish	FCD-FEX		14.1	6	2.1 \pm 1.67	1.35
		FCD-FEN		15.0	3	2.6 \pm 2.25	2.14
		FEX- TM		12.7	16	1.6 \pm 1.02	1.53
		FCD- TM		26.8	29	3.5 \pm 1.54	2.98
		FCU- TM		3.0	4	0.7 \pm 0.95	0.25
		FEX-FCD		14.1	1	3.5	3.5
		TM- FCD		26.8	1	1.0	1.0
		TM- FEX		12.7	1	12.7	12.7

FCU was recaptured at FCD in 1991 and one trout tagged at TM in 1990 was recaptured at FEX in 1991 further supporting limited fall to early spring movement.

During the pre-operational period (1984-1985) the movements of 50 brook trout were known. Six of these fish moved upstream but did not cross under the antenna, 43 moved upstream past the antenna, 1 moved downstream but did not cross under the antenna, and no marked brook trout were observed moving downstream past the antenna. During the transitional period (1986-1989), the movement of 10 brook trout were known. Four of these fish moved upstream but did not cross under the antenna, 3 moved upstream past the antenna, 2 moved downstream but did not cross under the antenna, and 1 brook trout moved downstream past the antenna. A χ^2 analysis of these data indicates that a significantly higher percentage of brook trout moved upstream past the antenna during the pre-operational period than did so during the transitional period ($\chi^2=17.73$, $df=3$, $p<0.05$).

To more closely examine the movement of brook trout under the ELF antenna, in 1990 an additional net site (FEN) was established upstream from the antenna approximately 400 meters from FEX. Of 42 fish captured and marked at FEX in 1990, none were recaptured at FEN. Additionally, a radio-marked brook trout released on the upstream side of FEX failed to move upstream past the antenna in the 10 day period during which it was monitored. In 1991, only 1 of 109 brook trout tagged at FEX was recaptured at FEN. However, 3 fish marked at FCD were recaptured at FEN and 2 radio tagged brook trout from FEX were followed past the antenna directly, indicating that the antenna electromagnetic field did not impede passage. The most significant evidence of passage, however, was shown by 33 fish marked at FCD and 23 fish marked at FEX being recaptured at the TM site in 1991. No brook trout moved downstream past the antenna in either 1990 or 1991.

A range of individual movement times (number of days it took an individual fish to move from the point of marking to another site) for pre-operational years, transitional years, and post-operational years was set up in Figure 8.2a and Figure 8.2b. In addition, a cumulative frequency distribution of days it took individual fish to move during the pre-operational, transitional, and post-operational periods is given in Figure 8.3. No difference in the movement pattern (days to move) was detectable when pre-operational, transitional, and post-operational periods were compared (Log-rank test; $\chi^2=3.15$; $df=2$; $p>0.05$). At this time, no definitive conclusions can be drawn as to ELF effects on movement; however, it appears that ELF does not have an effect on movement because there are similar distributions of days since tagged values in pre-operational

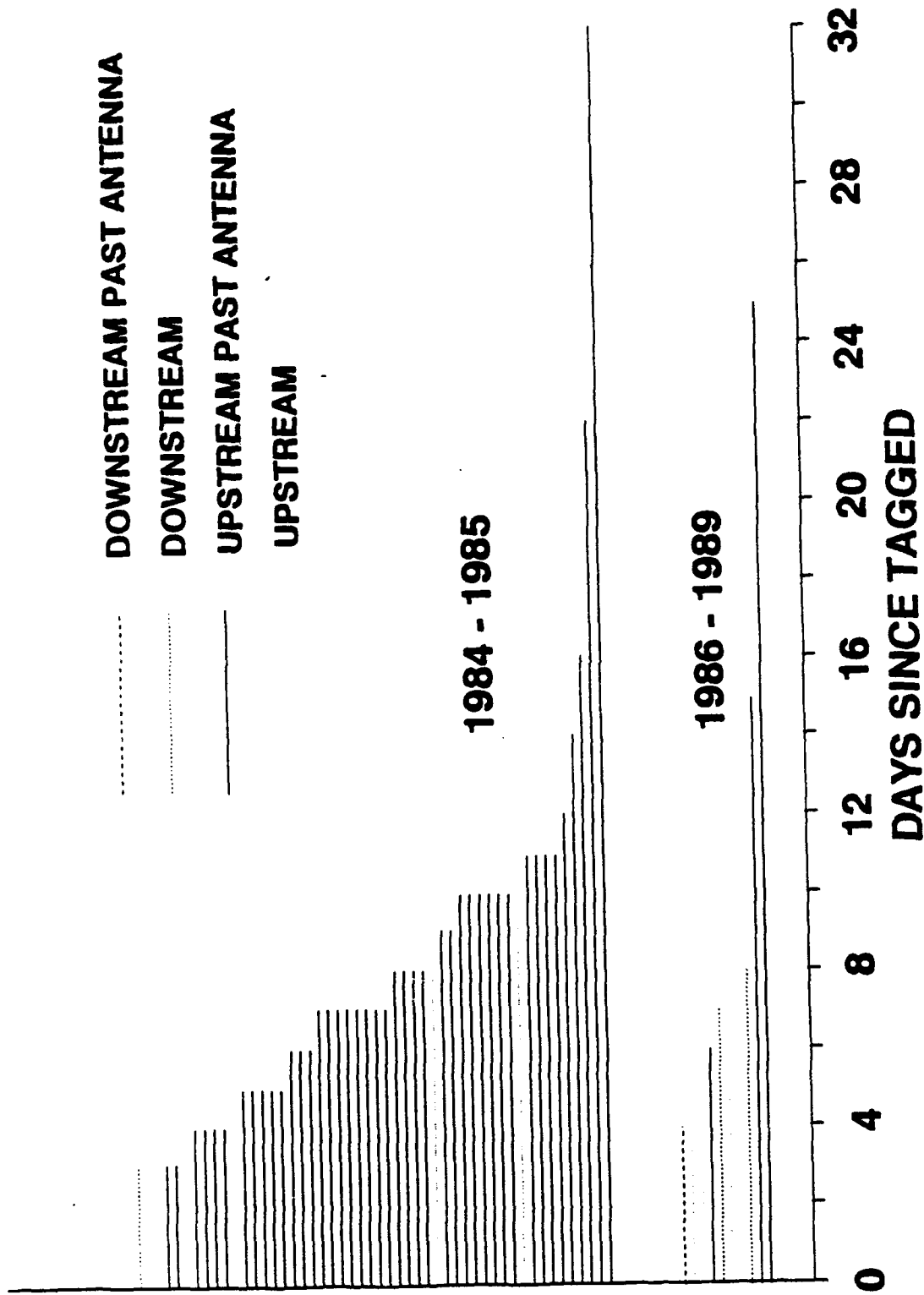


Figure 8.2a. Range of individual movement times of brook trout during pre-operational (1984-1985), and transitional (1986-1989) study periods.

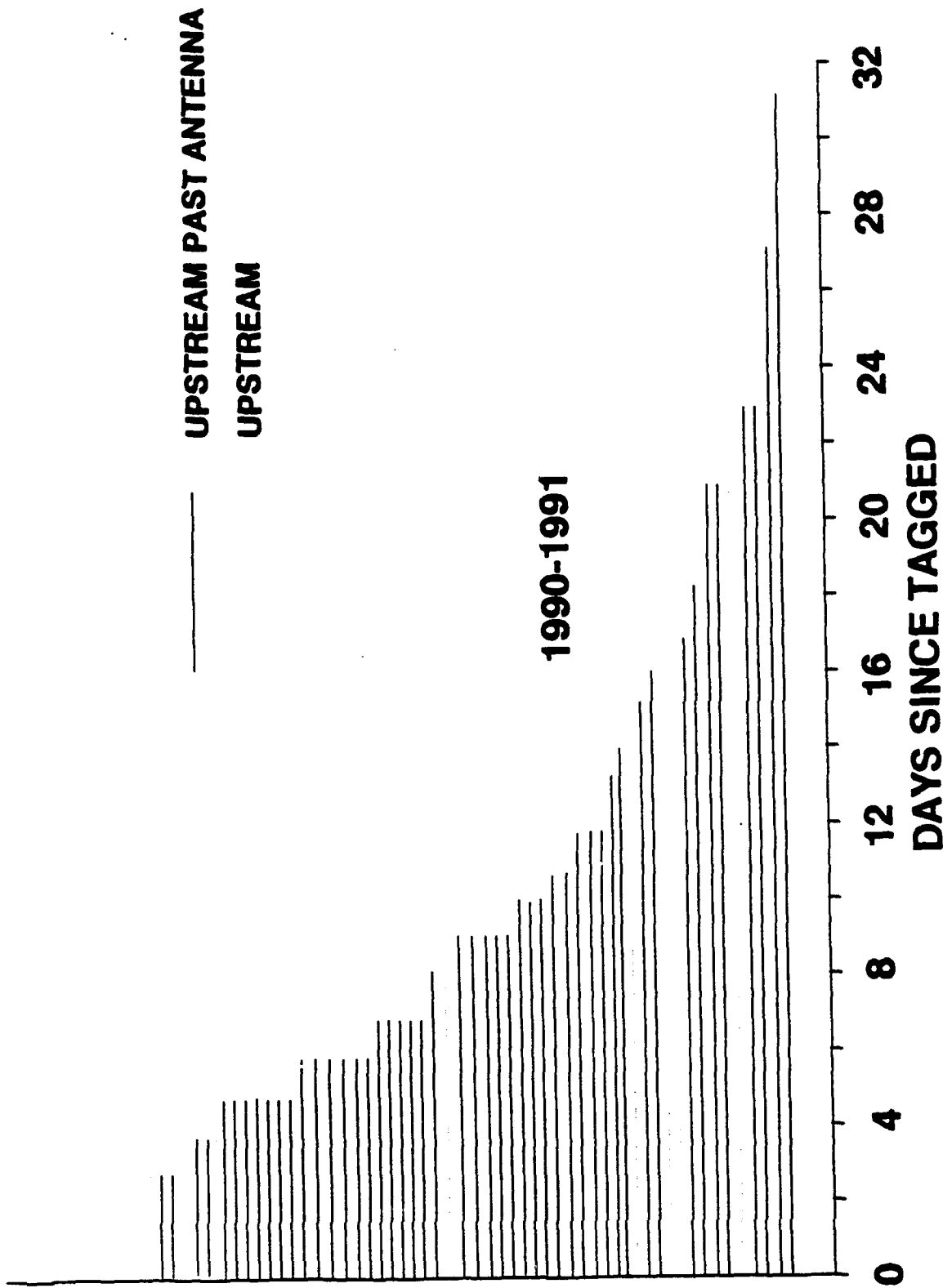


Figure 8.2b. Range of individual movement times of brook trout during post-operational (1990-1991) study period.

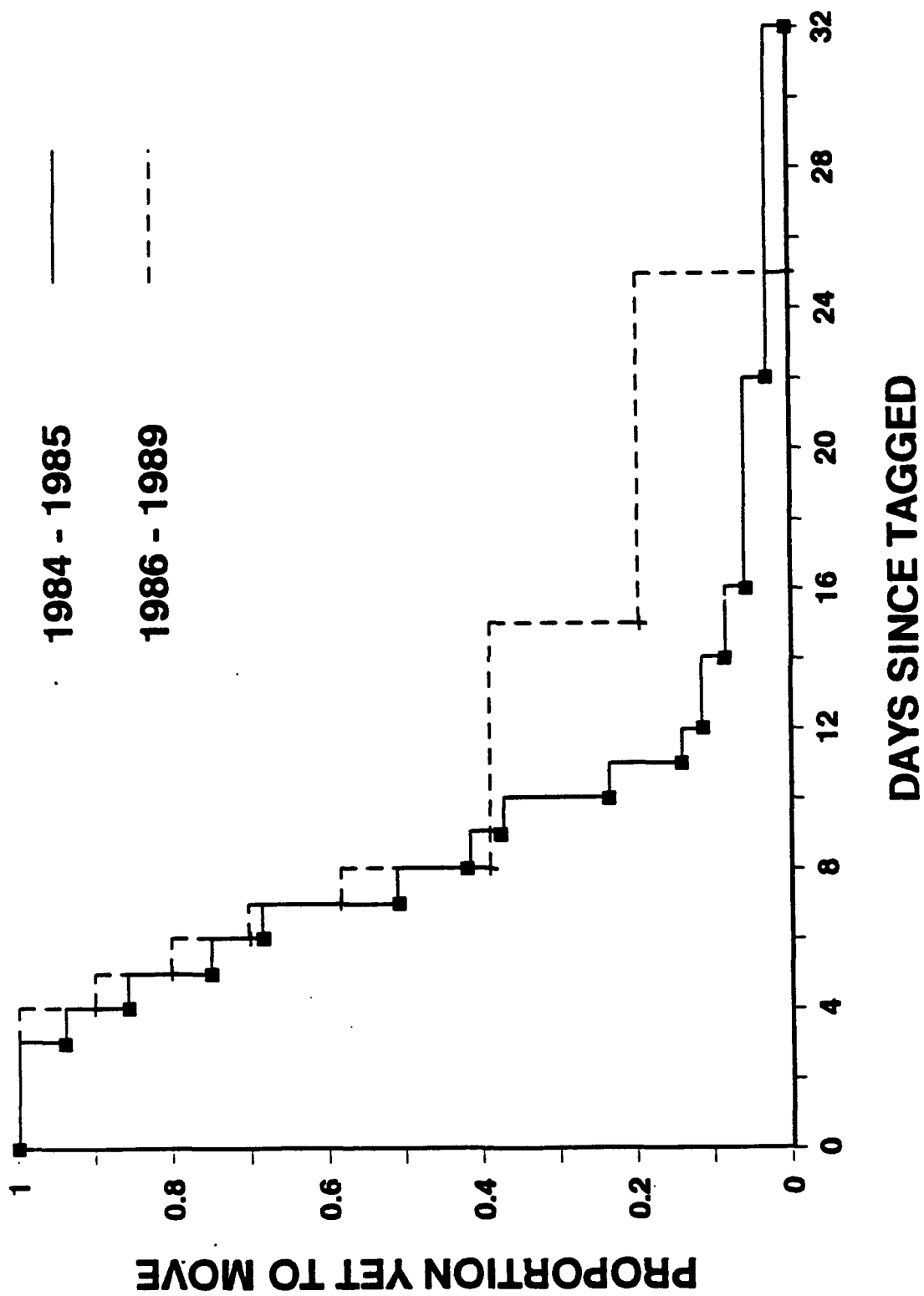


Figure 8.3. Movement distribution, in days since tagging, for individual brook trout during the pre-operational and transitional study periods.

years, transitional years, and post-operational years.

One possible complicating factor in the movement rate analysis observed during the 1990 season was the presence of beaver dams as barriers to movement during summer low water periods. Three of five brook trout tagged with radiotelemetry transmitters were observed to be stopped by beaver dams during low flow periods in mid July. Two of the fish spent more than 7 days directly below the structures. The trout then retreated to deep holes from 1 to 2 km below the dams where contact was lost as transmitter batteries failed after approximately 30 days. Contact with the other fish was lost the day after it was observed below a small dam upstream of FCD. It is doubtful that this dam was a hindrance to movement, however, and initial conclusions are that this fish was lost to predation or to transmitter failure. These results may also explain low recapture rates observed during the transitional and post-operational years. A major dam made in 1986 upstream of FEX was destroyed during the spring of 1991 by high flows. This may partially explain the high recapture percentages observed at the TM weir site in 1991 and the low recapture percentages from 1986 through 1990.

From a bioenergetic standpoint, brook trout in the Ford River appear to utilize Two Mile Creek for thermal refuge since temperatures there, as opposed to the upper Ford River, stay closer to optimum growth temperature. Groundwater inputs may have kept TM at or near 16 C during all years except 1987 when reduced groundwater inputs from abnormally low precipitation during winter and spring may have resulted in higher temperatures. Temperatures in all years were lower at TM than at FCU.

C. Proximate Causes of Brook Trout Movement

Mean daily water temperature patterns were similar at FEX and FCD. Temperature patterns between years, however were highly variable, especially during late spring and early summer (Figure 8.4). In all years peak movement times coincided with mean daily temperatures exceeding the optimum for brook trout growth (16 C). In 1984 temperatures exceeded the optimum during the first week of June and the subsequent peak in mean daily catch occurred during that week. For 1985, 1989, and 1990 mean daily temperatures peaked past the optimum during the last week of June and peak movement times for these three years were the first week of July for 1985, the last week of June for 1989, and the first and second week in July for 1990. Mean daily temperatures in 1986, 1988, and 1991 peaked during the last week of May and movements in 1986 and 1988 peaked during the

first week of June and in 1991 during the second and third week of June. In 1987, water temperature and movement peaked during the third week of June.

Two additional factors which influenced brook trout movement patterns were discharge and population size. Analysis of discharge during the spring - early summer movement period at FCD showed there was high variability among years (Figure 8.5). Discharge patterns in 1984 and 1991 showed periodic peaks throughout the year indicating that evenly spaced precipitation events occurred. Patterns for 1985, 1987, 1989, and 1990 displayed high spring - early summer discharge and low values during summer. 1986 and 1988 patterns showed low spring and summer values and increased flow in fall. Upstream directed movements occurred during all years despite different flow patterns. However, daily movements were strongly associated with peaks in daily discharge.

Fewer fish moved in 1986, 1988, 1989, and 1990 probably due to low trout populations during these years. When populations are low, individuals may be able to find adequate coldwater microhabitats without intra or interspecific competition from other fishes. In summary, it appears that when the brook trout population is abundant, water temperatures are suboptimal ($>16^{\circ}\text{C}$) and flows are high, substantial upstream movement, characterized by high daily catches in spring and/or early summer, occurs.

D. Brook Trout Movement Rates

The rates and direction of brook trout movement have the potential to be a very sensitive indicator of ELF effects. If trout have difficulty orienting through the ELF corridor, we would expect to observe disoriented behavior and decreased movement rates, particularly at FEX. Average movement rates for pre-operational, transitional, and post-operational periods are given in Table 8.3. A one-way ANOVA detected no significant differences in movement rates among the three different periods. A summary of brook trout site to site movement for all years is given in Table 8.2. Angler tag return data supported the above trends and indicated that brook trout move at a mean rate of 2.3 km/day in an upstream direction, similar to rates recorded from our sampling gear.

E. Gear Calibration and Brook Trout Population Estimates.

It was determined through analysis of length frequency distributions from fyke net catches that all brook trout 120

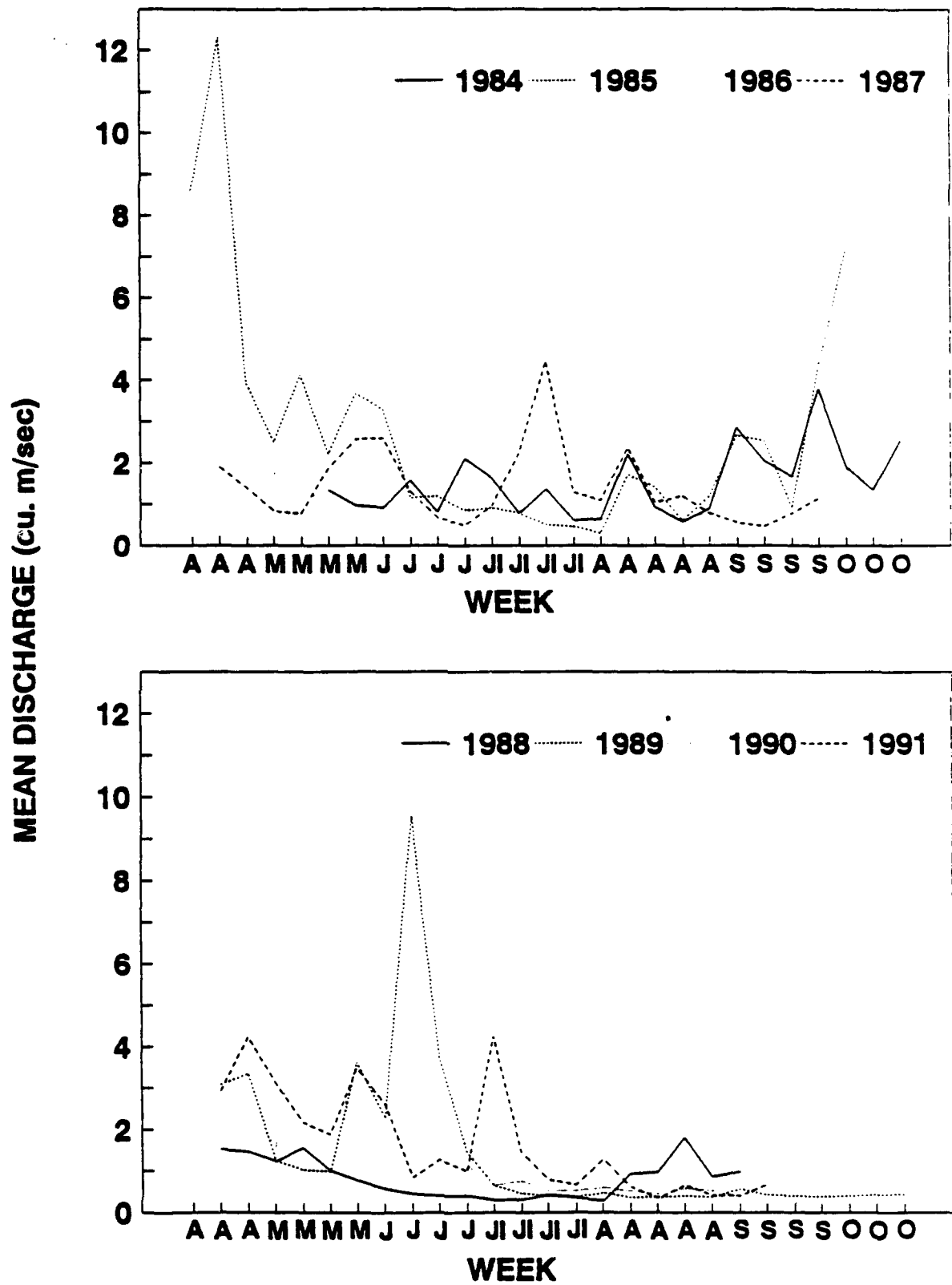


Figure 8.5. Mean daily discharge calculated on a weekly basis at FCD from 1984-1987 and 1988-1991.

Table 8.3. One way ANOVA between pre-operational (1983-1985), transitional (1986-1989), and post-operational (1990-1991) brook trout movement rates.

	1984-1985	1986-1989	1990-1991
N	50	10	56
MEAN	3.14	2.55	2.70
VARIANCE	2.21	3.28	2.70
NO SIGNIFICANT DIFFERENCE ($F_{2,113}=1.23$, $p>0.05$)			

mm and greater are vulnerable to the gear. Length frequency distributions from two brook trout population estimates taken by the Michigan Department of Natural Resources at a site approximately 0.62 miles upstream of FCD in 1985 were compared to length frequency distributions from fyke net catches in that year. In addition, brook trout population estimates were obtained 1 mile downstream from FCD in 1986, 1987, 1988, 1989, and 1990 by ELF personnel. Length frequencies obtained from these estimates (Figures 8.6a and b) were compared to length frequency distributions of the fyke net catches during each year to determine the percent of the population vulnerable to our gear (Table 8.4). Brook trout population estimates in 1986, 1987, 1988, 1989 and 1990 downstream of the FCD site revealed low densities of fish, especially those under 120 mm. MDNR estimates on June 27, 1985 and September 19, 1985 revealed higher numbers of young-of-the-year fish than those obtained by ELF personnel. Only one brook trout was captured on five successive sampling periods during 1989 and 2 sampling periods in 1990 so these data are not presented in this report.

Population estimates were obtained 1.6 miles downstream of the FEX site in 1987, 1988, 1989, and 1990. Analysis of the length frequency distributions of net catches at FEX and electrofishing catches (Figure 8.7) near FEX in 1987 through 1988 indicate that a higher number of fish smaller than 120 mm were present than at FCD. The proportion of fish from these estimates vulnerable to the fyke nets are reported in Table 8.4. Only three brook trout were captured on six successive electrofishing sampling periods at the site downstream from FEX in 1989. All three fish were captured on August 21, 1989 and were larger adult fish. Only 4 brook trout were captured during 2 sampling periods in 1990, 2 were yearling fish and the other 2 were adult fish. In 1991, a Peterson population estimate was attempted at TM where a logging operation had cleared the forest to the bank. A total of 7 trout were captured on the marking run which included 3 adults and 4 young of the year. No recapture run was attempted. These data are not included in this report.

F. Brook Trout Age and Growth

Age and growth analysis of Ford River brook trout have the potential to be very sensitive indicators of ELF effects. Brook trout in the Ford River show excellent growth when compared to populations in Carlander (1969). The length frequency distribution of catches at FCD and FEX for each year are given in Figure 8.8(a-c). Growth analysis was conducted using the length versus total scale radius

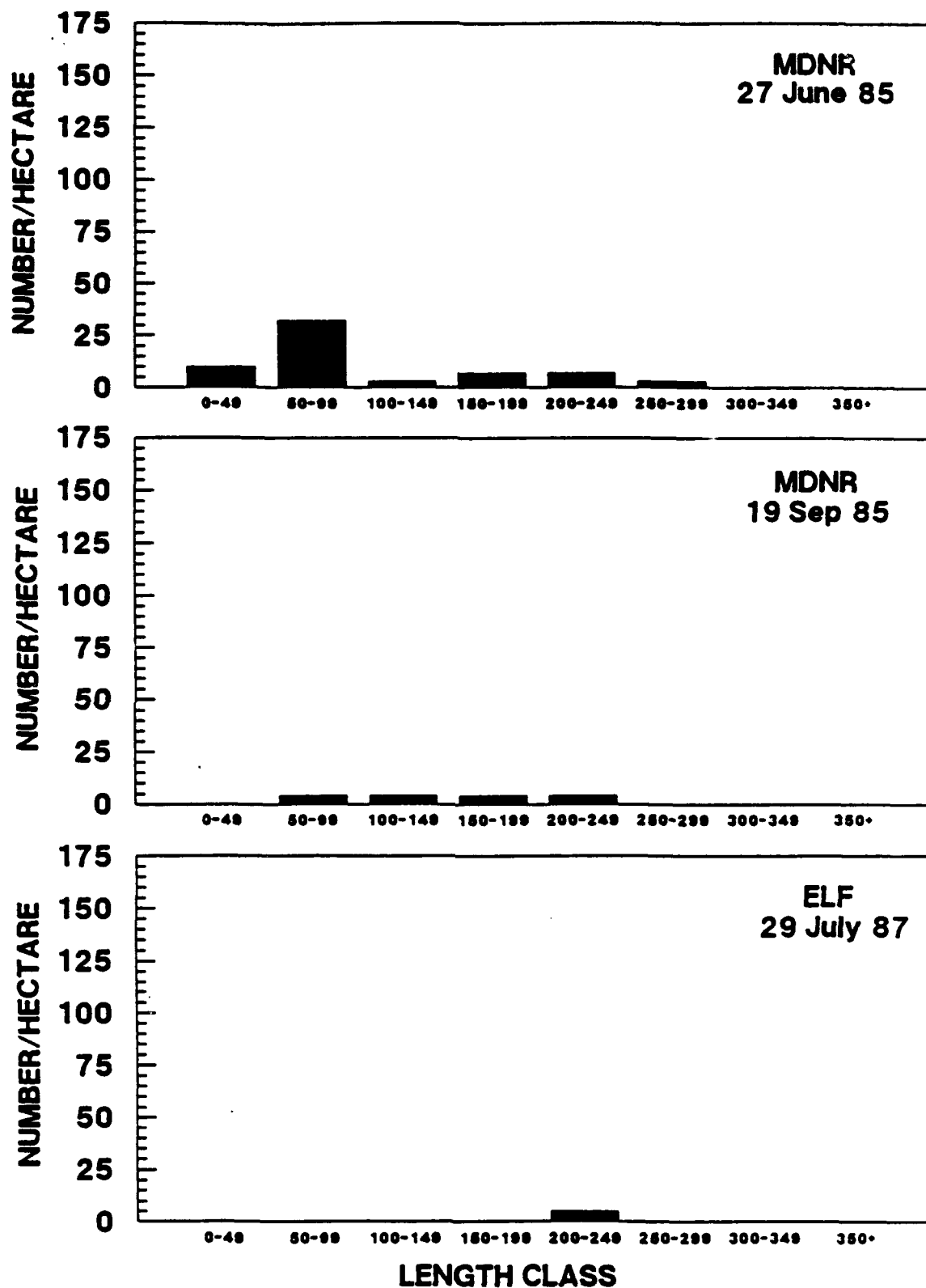


Figure 8.6a. Length frequency of brook trout taken by MI DNR and ELF personnel at FCD. Dates are included on graphs.

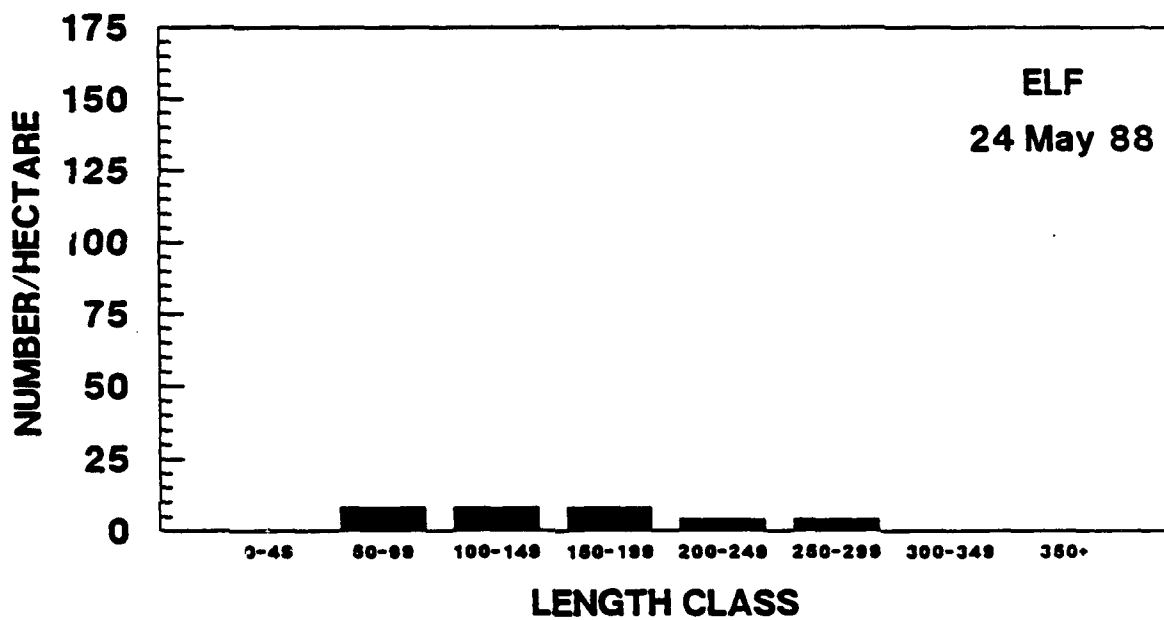
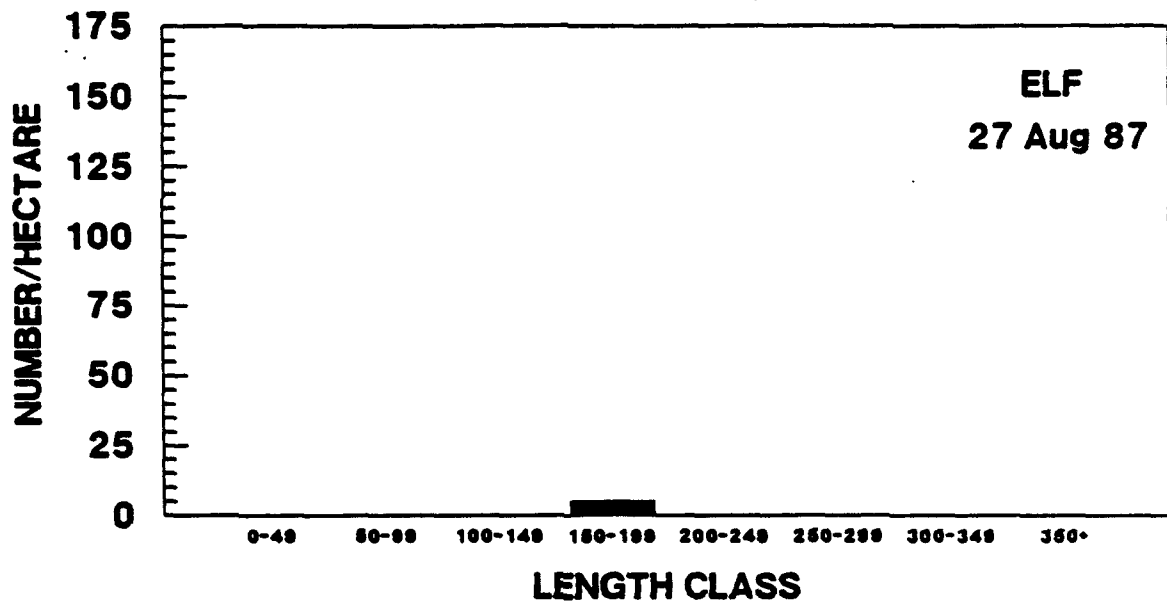


Figure 8.6b. Length frequency of brook trout at FCD taken by ELF personnel.

Table 8.4. Percent of the brook trout population vulnerable to the gear at FCD and FEX for years when population estimates were obtained. Assumes all fish > 120 mm are vulnerable to the gear.

DATE	SITE NEAR	PERCENT OF POP LESS THAN 120 mm	EXPECTED PROPORTION OF POP. VULNERABLE TO THE GEAR
Jun 27, 1985	FCD	66.7 %	33.3 %
Sep 19, 1985	FCD	25.0 %	75.0 %
Aug 07, 1986	FCD	0.0 %	100.0 %
Jul 29, 1987	FCD	0.0 %	100.0 %
Aug 27, 1987	FCD	0.0 %	100.0 %
May 24, 1988	FCD	29.0 %	71.0 %
Jul 7, 1988	FCD	0.0 %	100.0 %
Aug 26, 1988	FCD	0.0 %	100.0 %
Jun 21, 1989	FCD	0.0 %	100.0 %
Jul 19, 1989	FCD	0.0 %	100.0 %
Aug 23, 1989	FCD	0.0 %	100.0 %
Sep 21, 1989	FCD	0.0 %	100.0 %
Oct 22, 1989	FCD	0.0 %	100.0 %
Jun 28, 1990	FCD	0.0 %	100.0 %
Sep 5, 1990	FCD	0.0 %	100.0 %

Jul 1, 1987	FEX	12.5 %	87.5 %
Aug 26, 1987	FEX	16.6 %	83.4 %
Jul 31, 1988	FEX	45.5 %	54.5 %
Aug 4, 1988	FEX	90.0 %	10.0 %
May 23, 1989	FEX	0.0 %	100.0 %
Jun 21, 1989	FEX	0.0 %	100.0 %
Jul 19, 1989	FEX	0.0 %	100.0 %
Aug 21, 1989	FEX	0.0 %	100.0 %
Sep 23, 1989	FEX	0.0 %	100.0 %
Oct 20, 1989	FEX	0.0 %	100.0 %
Jun 28, 1990	FEX	0.0 %	100.0 %
Sep 5, 1990	FEX	50.0 %	50.0 %

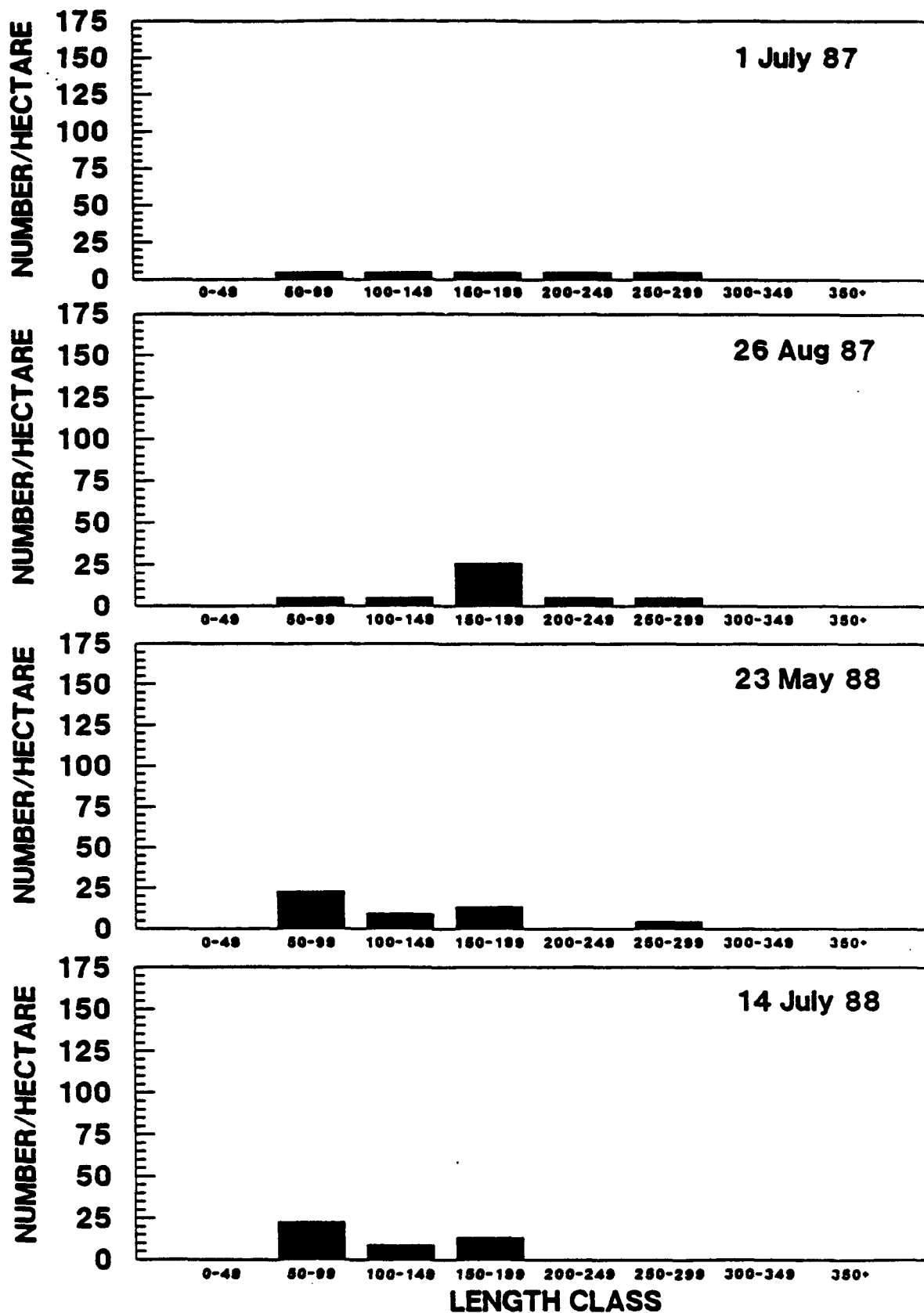


Figure 8.7. Length frequency of brook trout taken by ELF personnel at FEX.

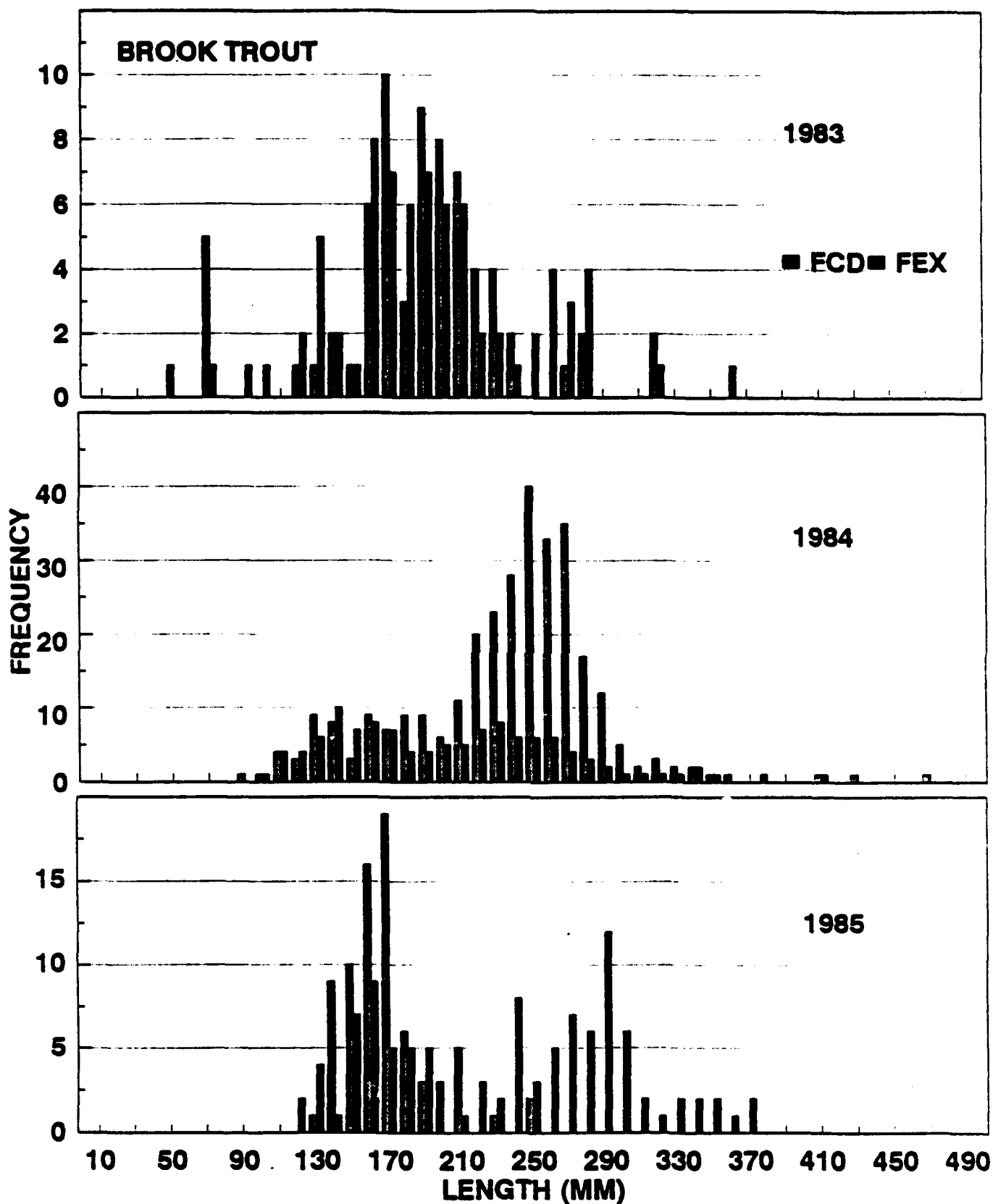


Figure 8.8a. Length frequency distribution of the annual catch of brook trout at FCD and FEX from 1983 to 1985.

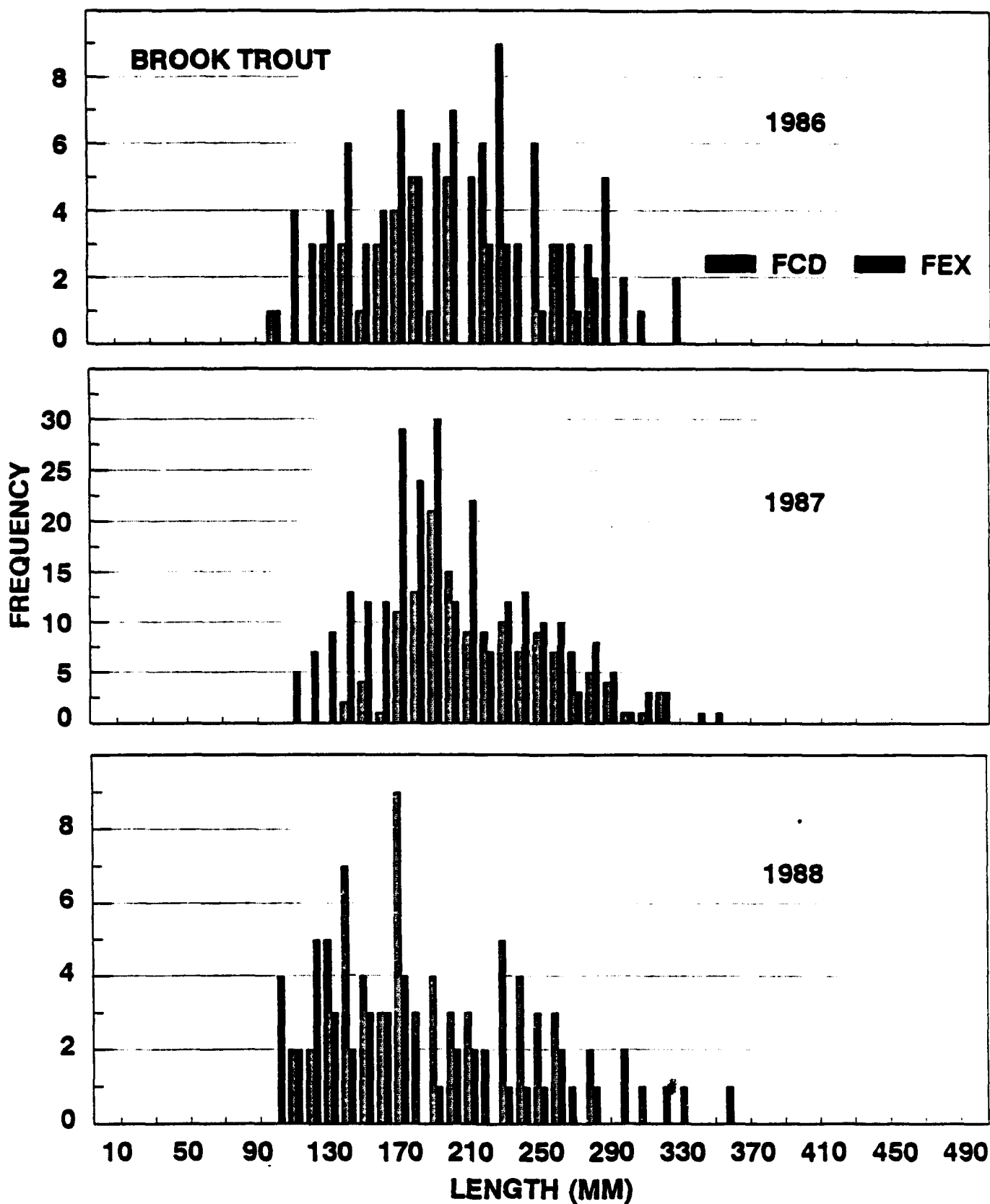


Figure 8.8b. Length frequency distribution of the annual catch of brook trout at FCD and FEX from 1986 to 1988.

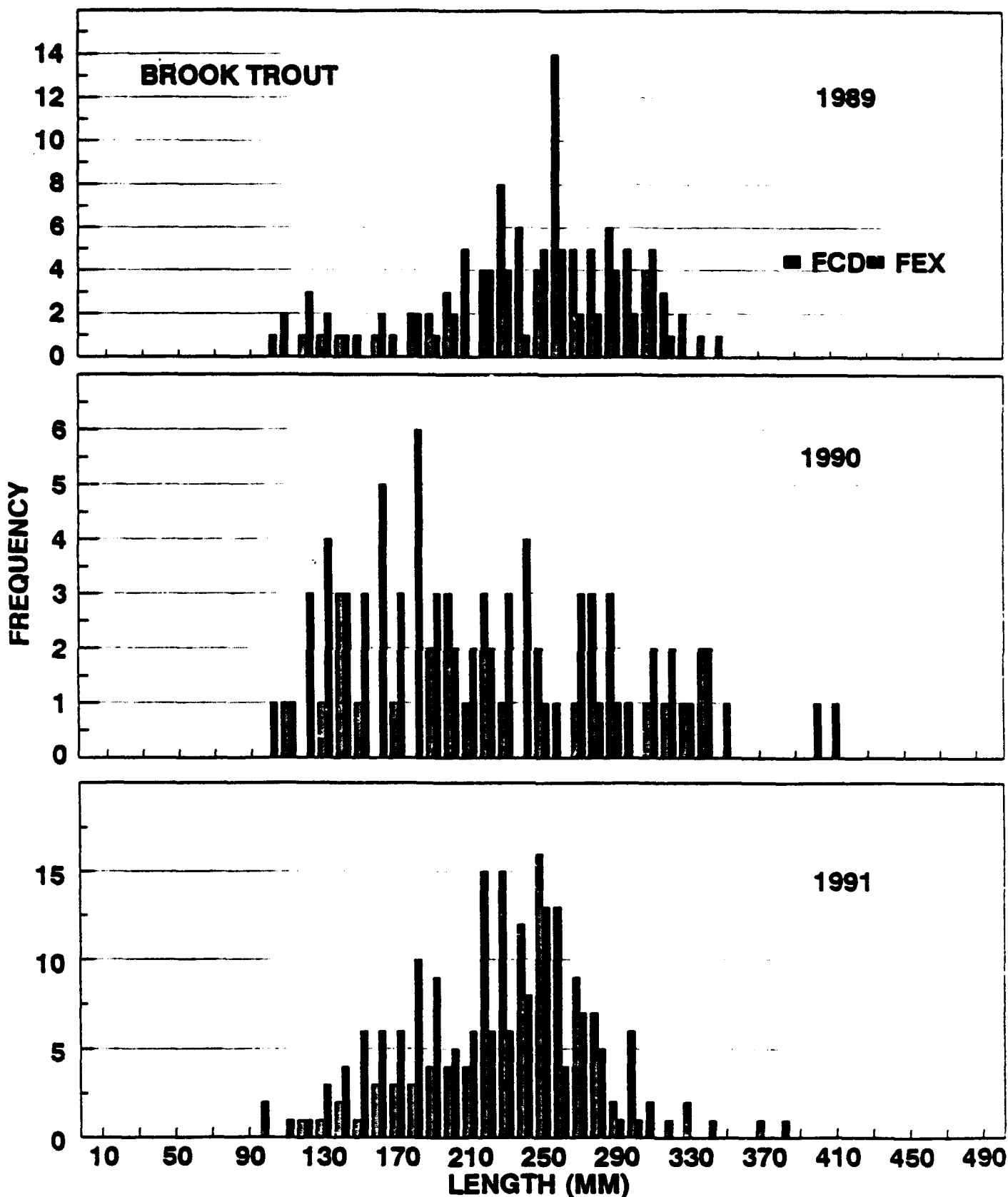


Figure 8.8c. Length frequency distribution of the annual catch of brook trout at FCD and FEX from 1989 to 1991.

regression equation. Covariance analysis was used to test for differences in the slopes of regression equations for length versus total scale radius data between FEX and FCD in each year (Table 8.5). The only years with significant differences between sites were 1984, 1986 and 1988. Covariance analysis was conducted to test for differences in the slopes of the regression lines among pre-operational, transitional, and post-operational years (Table 8.6 and Figure 8.9). A significant difference was detected among the three periods ($F_{5,765}=2.81$, $p<0.05$). The slopes of the regression lines for FCD were similar during the pre-operational and transitional periods. Also, the slopes of the regression lines for FEX were similar during the pre-operational and transitional periods. However, during the post-operational period the slopes of the regression lines at both FCD and FEX differed significantly from what they were in the previous two periods. Plots of all regression lines used in this analysis are shown on Figure 8.10(a-e).

Lee's phenomena (Ricker, 1975) was not seen in any year for Ford River brook trout. Brook trout age structure and growth analysis will be a key to defining any significant ELF effects. Decreased growth in brook trout, especially at FEX, is expected if the ELF system excludes fish from reaching cold water refuge areas.

G. Brook Trout Condition

Examination of brook trout condition was done using the relative weight methodology as described in element 7. The standard weight formula:

$$\log_{10} wt = -5.085 + 3.043 \cdot \log_{10} tl \quad (r=.999),$$

was determined using the 50th percentile equation from 45 brook trout populations reported in the literature.

Brook trout relative weight ranged from average to slightly below average from 1983 to 1991 when compared to values obtained from the above equation (Figure 8.11). Relative weight values steadily declined from 101.6 in 1983 to 89.0 in 1986. Condition improved in 1987 to 92.6 and maintained that level in 1988. Relative weight values for 1989 (95.6) and 1990 (98.3) were at levels near the literature mean. In 1991, relative weight values decreased to levels similar to 1987 and 1988 (94.0).

Length/weight regression analysis was also used to compare brook trout condition between FEX and FCD over all years (Table 8.7). No significant differences in the slopes of the regression lines were observed between sites over all years except in 1985 (ANCOVA, $p>0.05$) (Figure 8.12a-d).

Table 8.5. Regression equations used in between site comparison of length versus total radius data for 1983 through 1991.

YEAR SITE	REG EQUATIONS	SLOPE(df) (F)
1983		
FCD	$y=60.177 + 324.962x$	NS(1,142)
FEX	$y=57.025 + 352.025x$	(0.51)
1984		
FCD	$y=62.255 + 343.975x$	*(1,49)
FEX	$y=-10.11 + 518.964x$	(4.39)
1985		
FCD	$y=45.662 + 416.331x$	NS(1,28)
FEX	$y=9.556 + 489.439x$	(0.71)
1986		
FCD	$y=18.448 + 443.314x$	*(1,101)
FEX	$y=47.408 + 356.639x$	(4.36)
1987		
FCD	$y=89.657 + 284.874x$	NS(1,230)
FEX	$y=58.296 + 351.143x$	(3.11)
1988		
FCD	$y=91.162 + 197.896x$	*(1,17)
FEX	$y=3.186 + 435.569x$	(10.09)
1989		
FCD	$y=111.88 + 297.17x$	NS(1,55)
FEX	$y=103.52 + 347.91x$	(0.60)
1990		
FCD	$y=18.47 + 526.10x$	NS(1,42)
FEX	$y=22.51 + 500.29x$	(0.06)
1991		
FCD	$y=62.00 + 405.69x$	NS(1,77)
FEX	$y=45.62 + 410.89x$	(0.005)

* SIGNIFICANT $p<0.05$

Table 8.6. Regression equations used in covariance analysis of between period (pre-, trans-, and post-operational) comparisons of length versus total scale radius at FCD and FEX.

	EQUATIONS	n	SLOPE
PRE-OPERATIONAL (1983-1985)			
FCD	$y=52.01 + 361.59x$	119	a
FEX	$y=43.95 + 390.16x$	102	b
TRANSITIONAL (1986-1989)			
FCD	$y=63.46 + 355.77x$	179	a
FEX	$y=44.68 + 386.70x$	240	b
POST-OPERATIONAL (1990-1991)			
FCD	$y=48.78 + 439.61x$	79	c
FEX	$y=26.93 + 475.65x$	48	d

NOTE - Overall test for equal slopes using covariance analysis was significant ($p < 0.05$) with $F_{(3,765)} = 2.81$. Same letters indicate that periods have a similar slope using Tukey - Kramer Multiple Comparison Test, $\alpha = 0.05$ (Miller 1986).

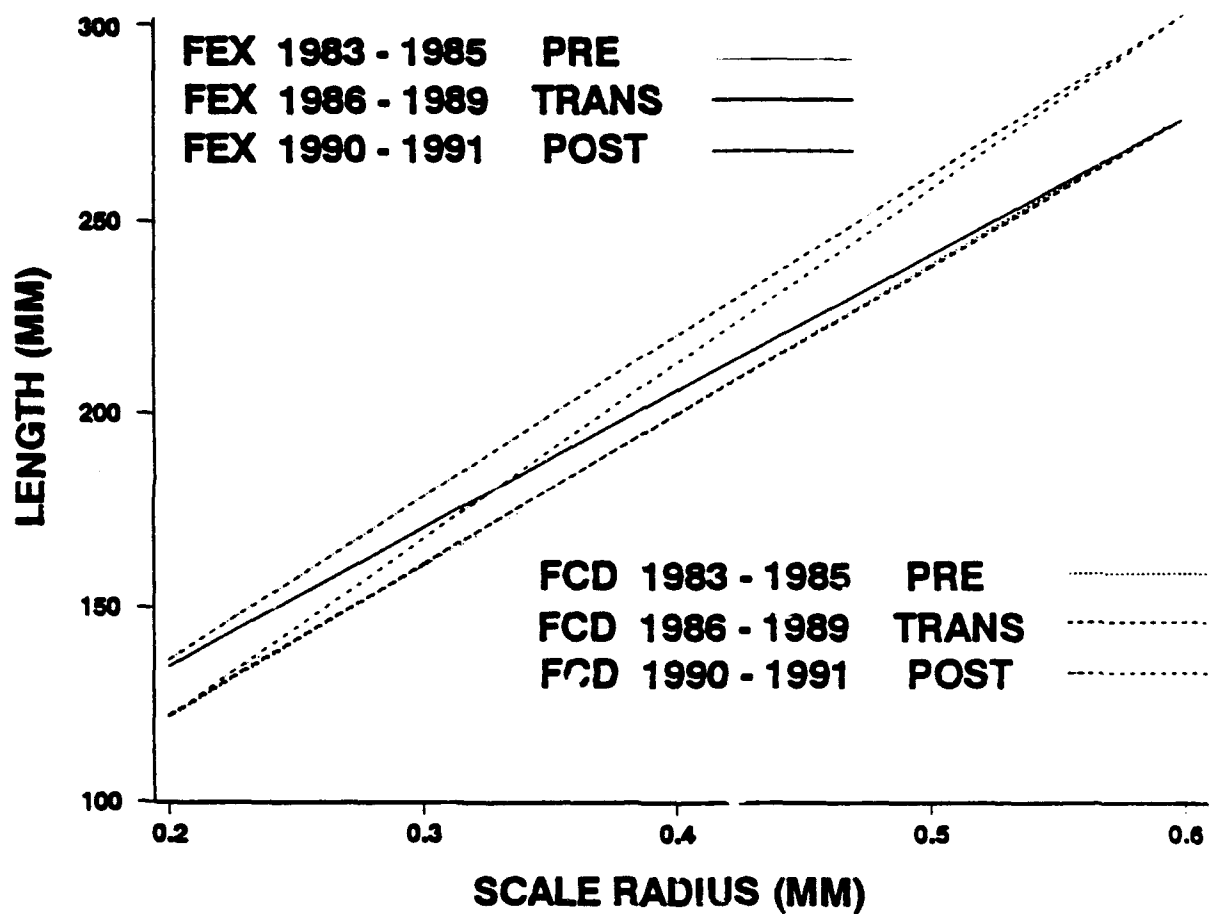


Figure 8.9. Plots of the regression lines used in the covariance analysis of length vs. total scale radius.

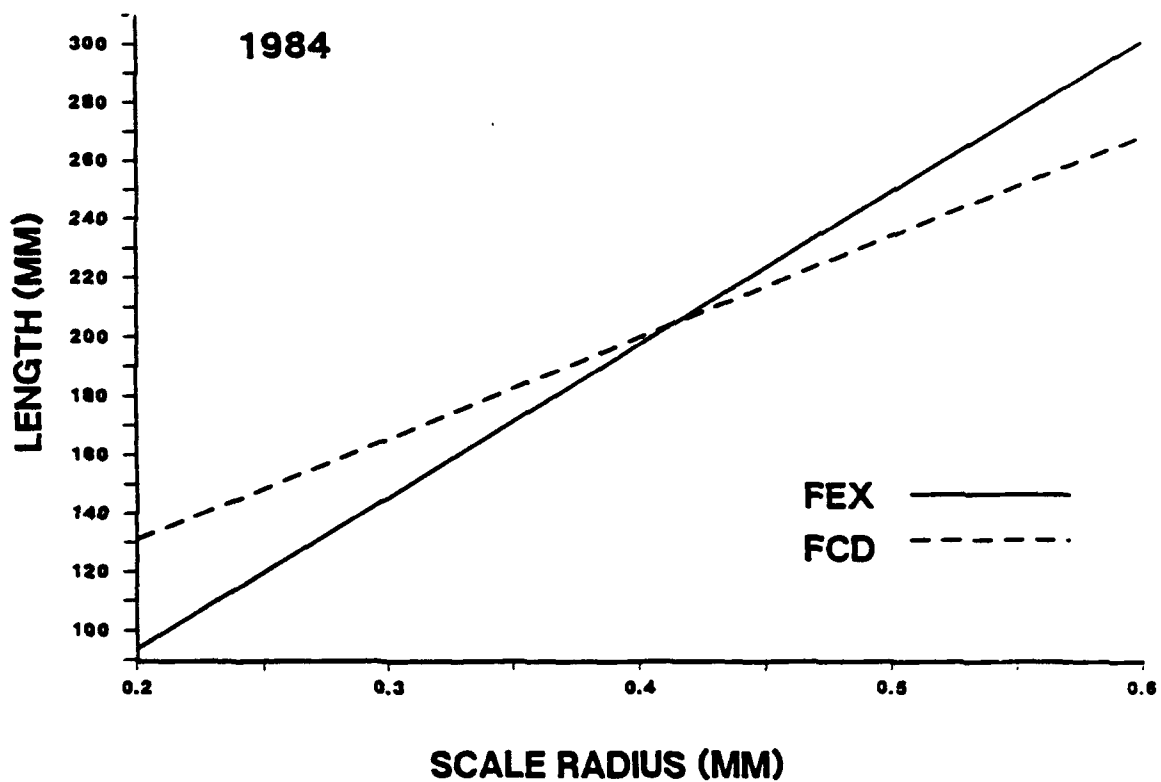
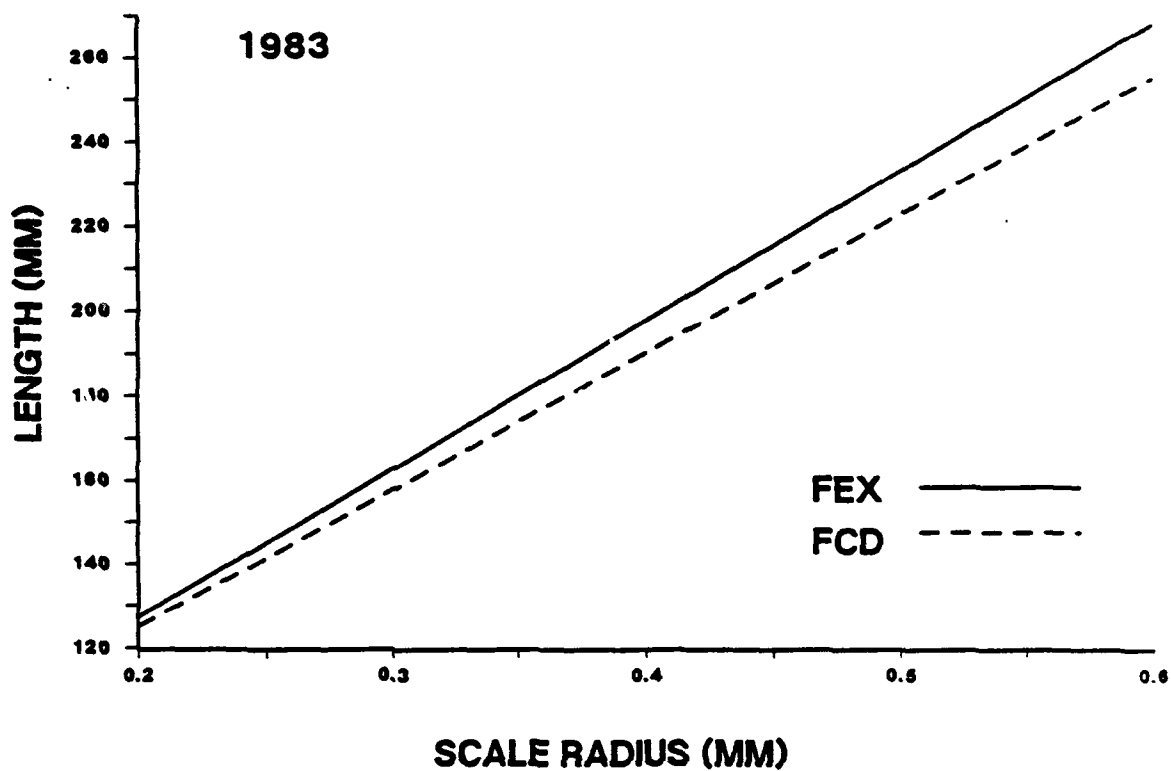


Figure 8.10a. Plots of the regression lines used in analysis of total fish length versus total scale radius between sites in 1983 and 1984.

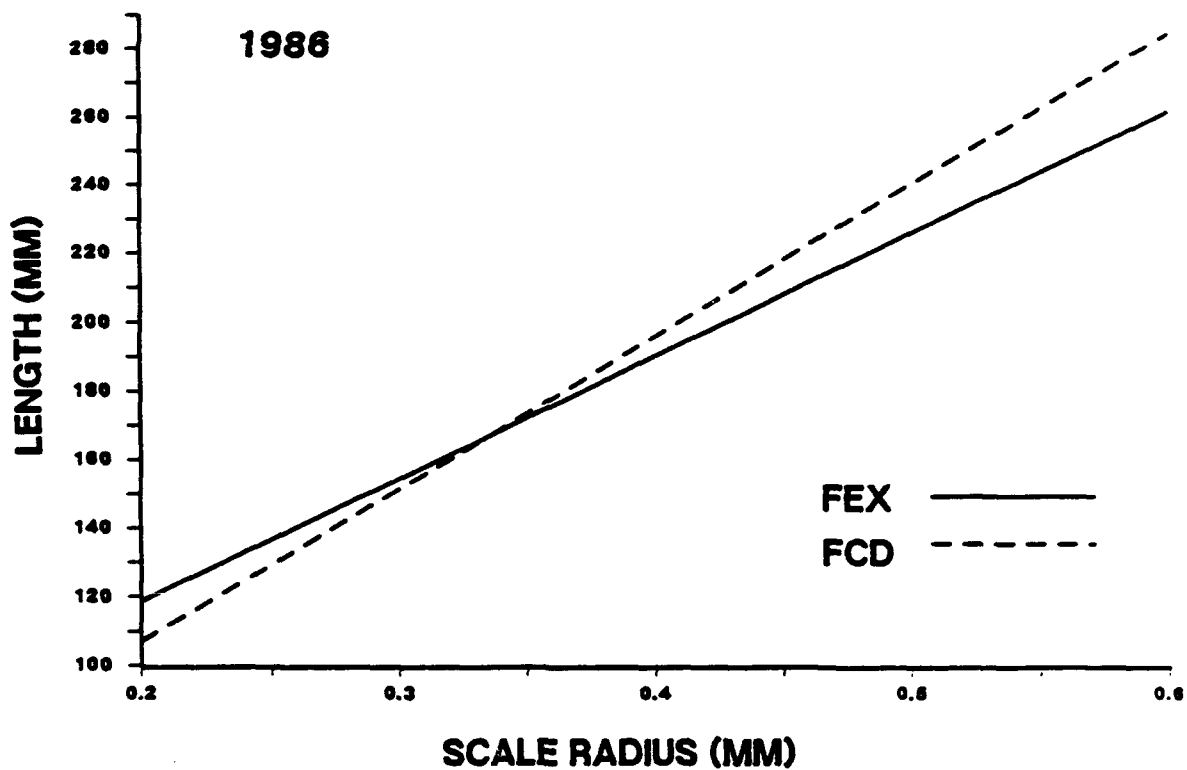
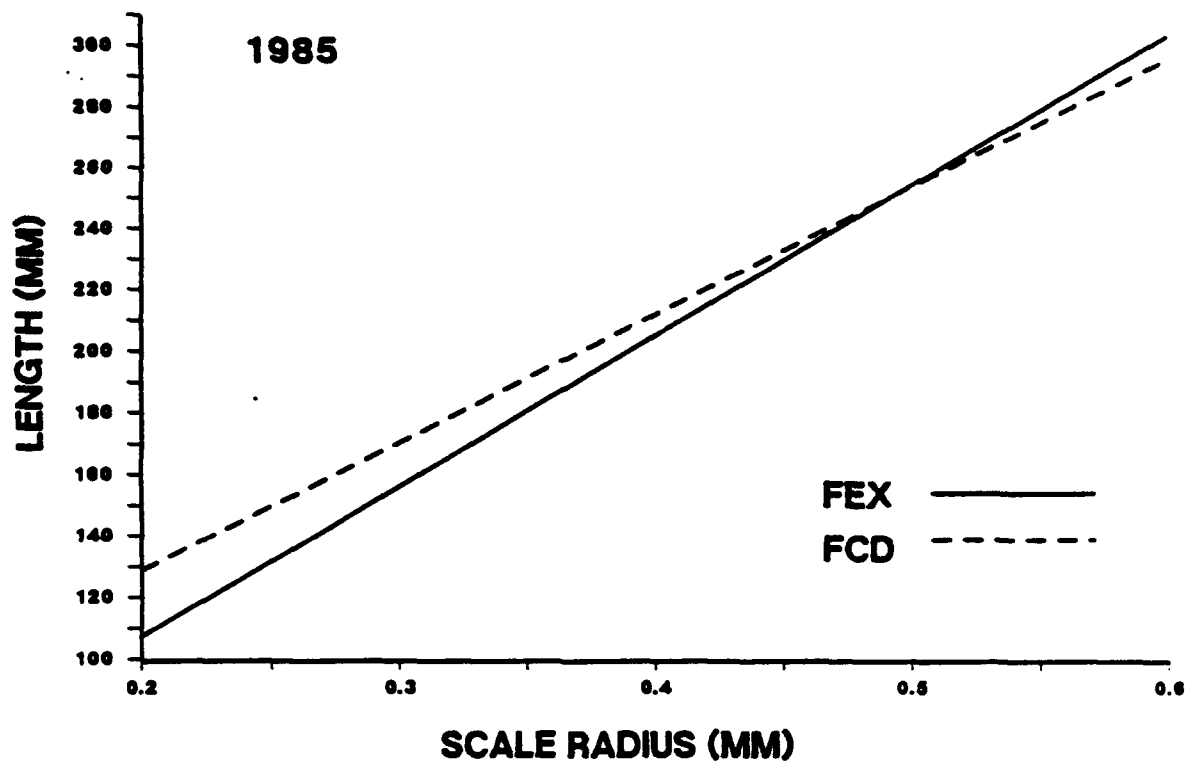


Figure 8.10b. Plots of the regression lines used in analysis of total fish length versus total scale radius between sites in 1985 and 1986.

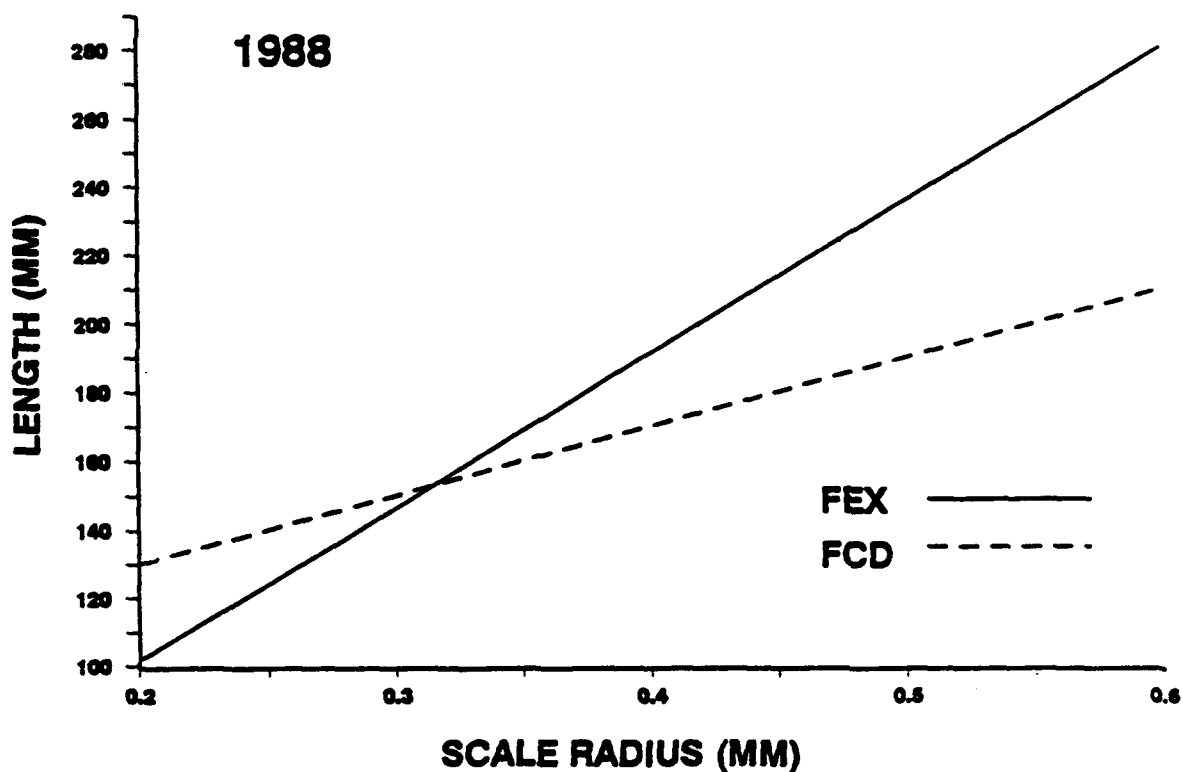
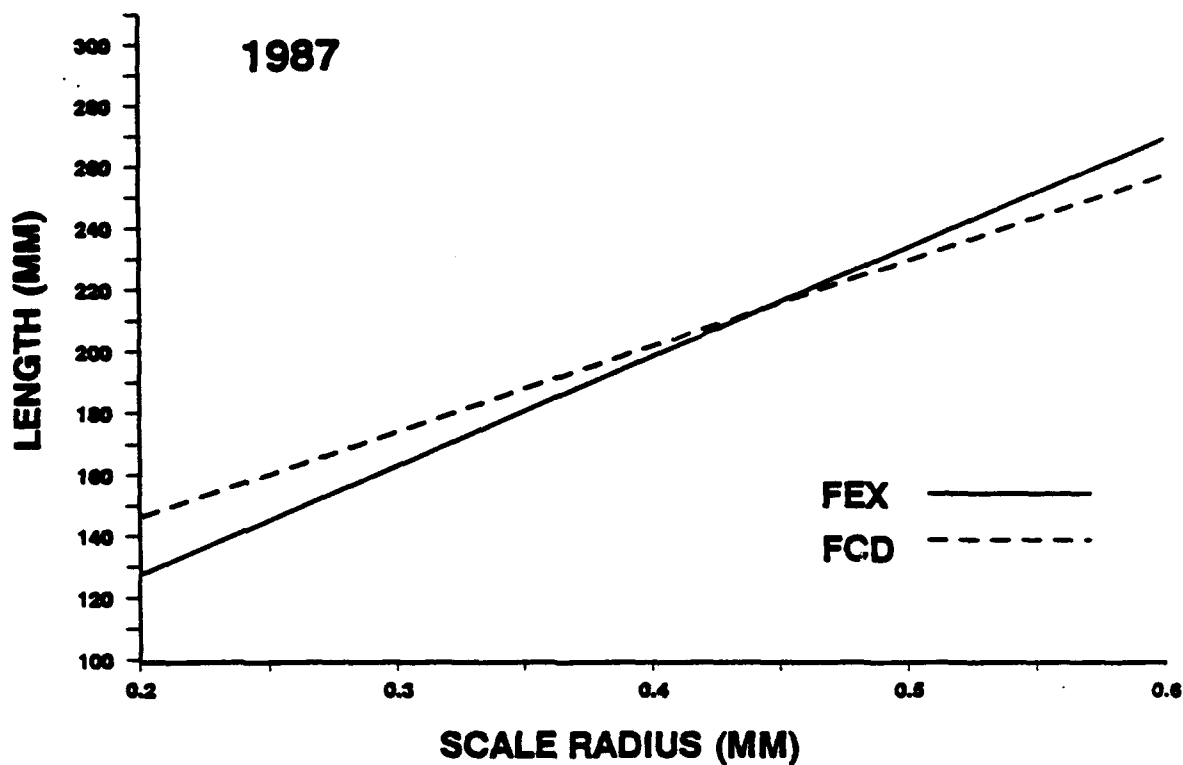


Figure 8.10c. Plots of the regression lines used in analysis of total fish length versus total scale radius between sites in 1987 and 1988.

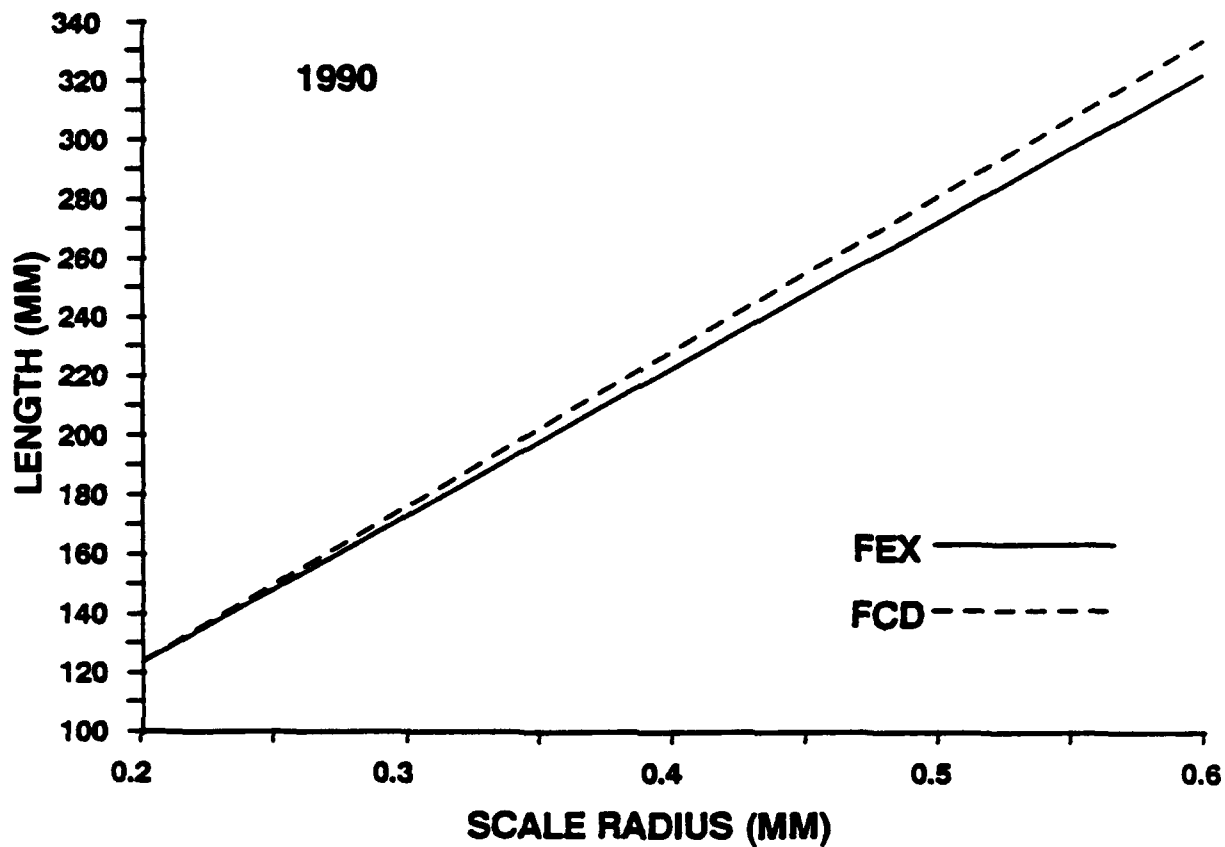
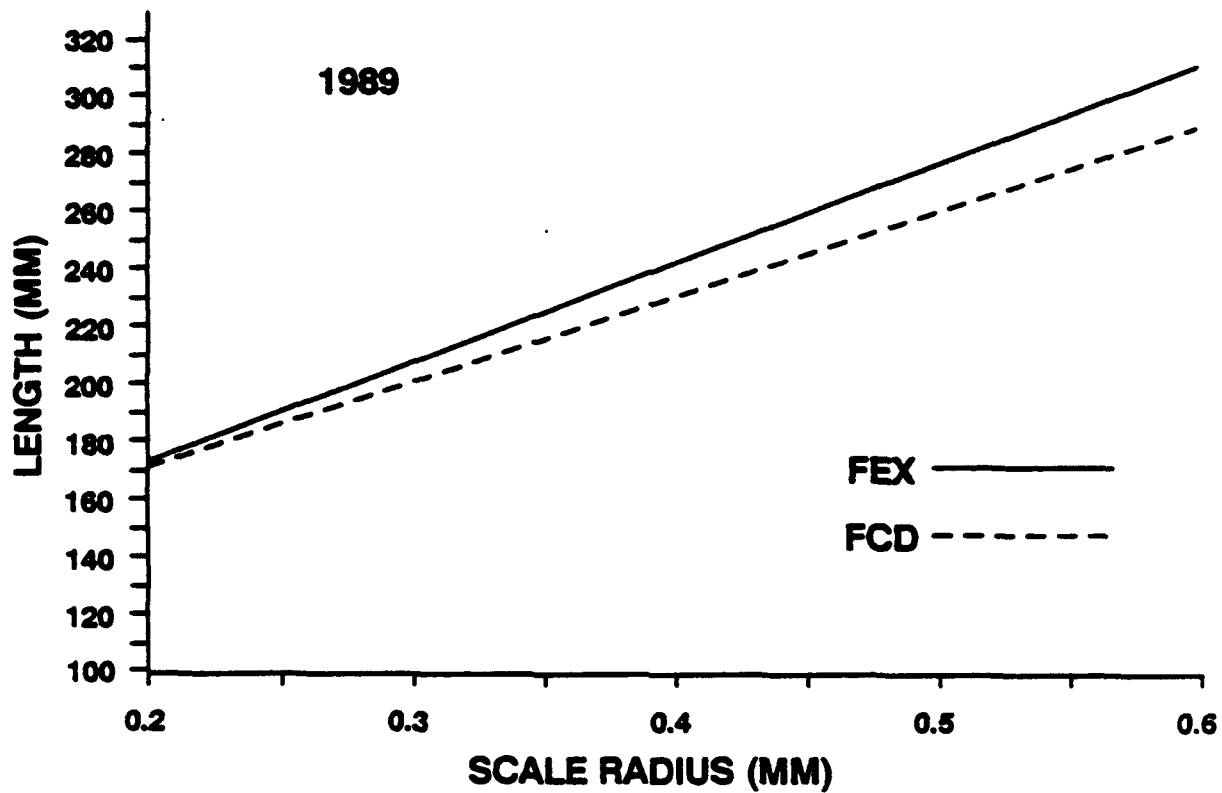


Figure 8.10d. Plots of the regression lines used in the analysis of total length versus total scale radius between sites in 1989 and 1990.

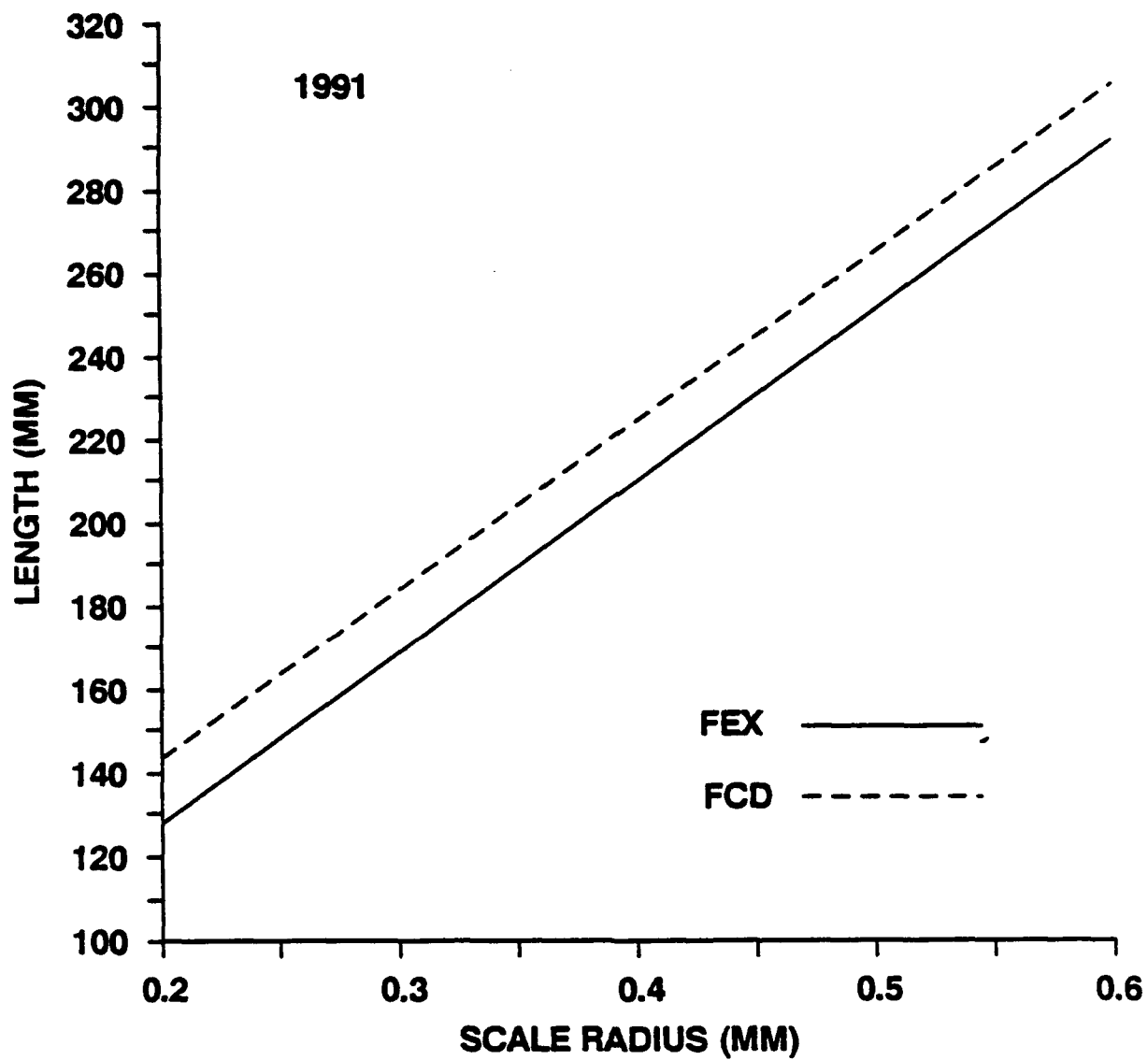


Figure 8.10e. Plots of the regression lines used in analysis of total fish length versus total scale radius between sites in 1991.

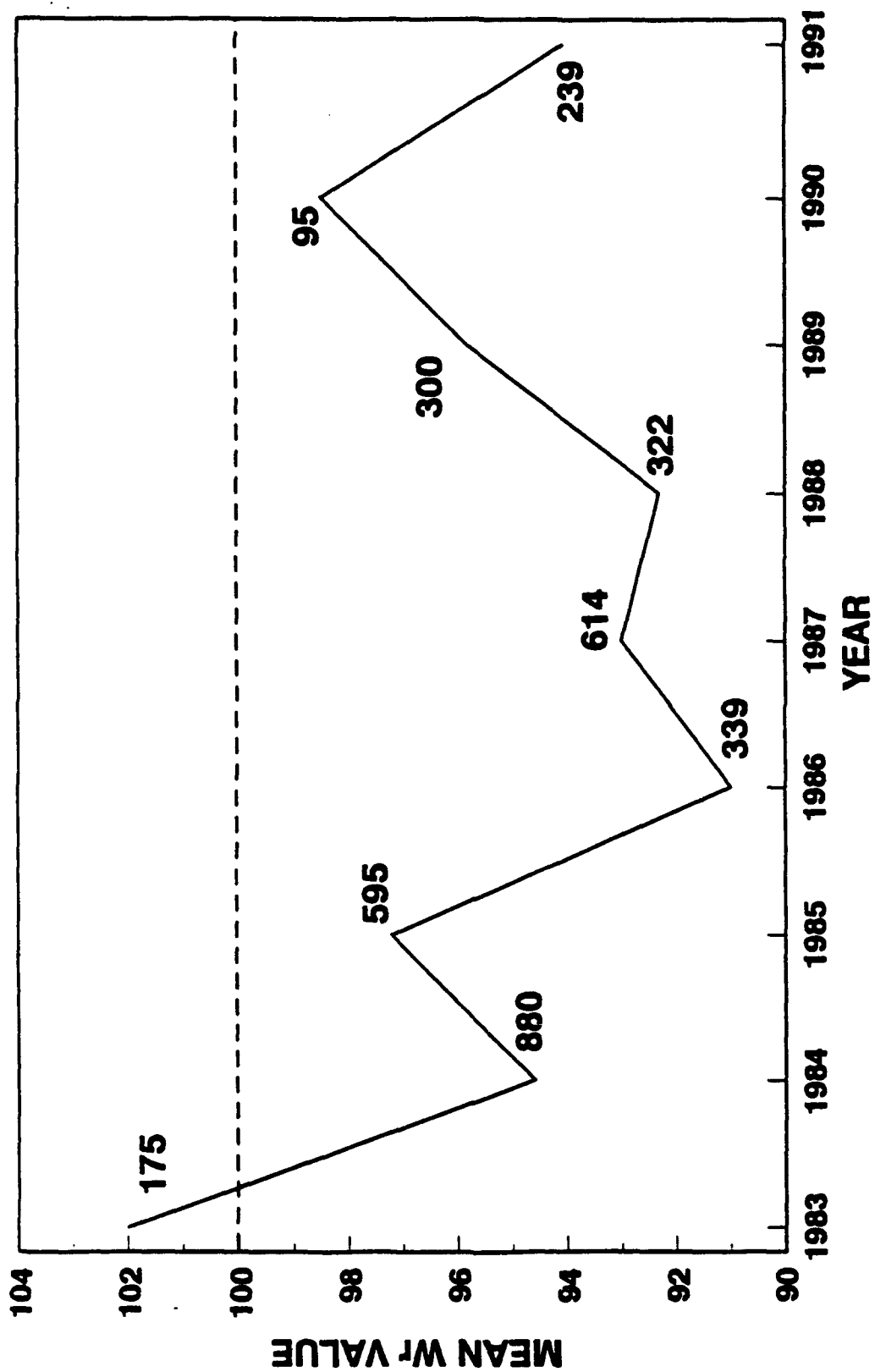


Figure 8.11. Brook trout unweighted relative weight values from the Ford River.
Numbers adjacent to means refer to sample size used in calculation.

Table 8.7. Regression equations used in brook trout condition analysis between FEX and FCD in each year.

EQUATION LOG(weight) = a + bLOG(length) y = log(weight) x = log(length)				
YEAR	FEX (n)	FCD (n)	Slope(df) (F)	Intrcpt(df) (F)
1984	y=-5.358+3.143x (115)	y=-5.272+3.115x (251)	NS(1,360) (0.103)	NS(1,361) (2.709)
1985	y=-5.767+3.328x (103)	y=-5.528+3.220x (134)	*(1,233) (4.930)	NT NT
1986	y=-5.181+3.056x (68)	y=-5.391+3.160x (69)	NS(1,133) (0.081)	NS(1,134) (3.710)
1987	y=-5.314+3.134x (252)	y=-5.434+3.185x (139)	NS(1,387) (1.030)	NS(1,388) (0.170)
1988	y=-5.192+3.073x (39)	y=-5.200+3.077x (69)	NS(1,104) (0.002)	*(1,105) (0.001)
1989	y=-5.464+3.216x (56)	y=-5.510+3.225x (95)	NS(1,147) (0.020)	*(1,148) (9.560)
1990	y=-5.310+3.136x (61)	y=-5.479+3.207x (33)	NS (1,92) (0.269)	NS (1,93) (0.022)
1991	y=-5.370+3.160x (103)	y=-5.330+3.150x (120)	NS (1,219) (0.005)	*(1,220) (4.85)

* SIGNIFICANT alpha = 0.05

NOTE - All F tests from analysis of covariance. If the slopes are the same then a test for a common intercept was performed. If the slopes are different a test for a common intercept cannot be done.

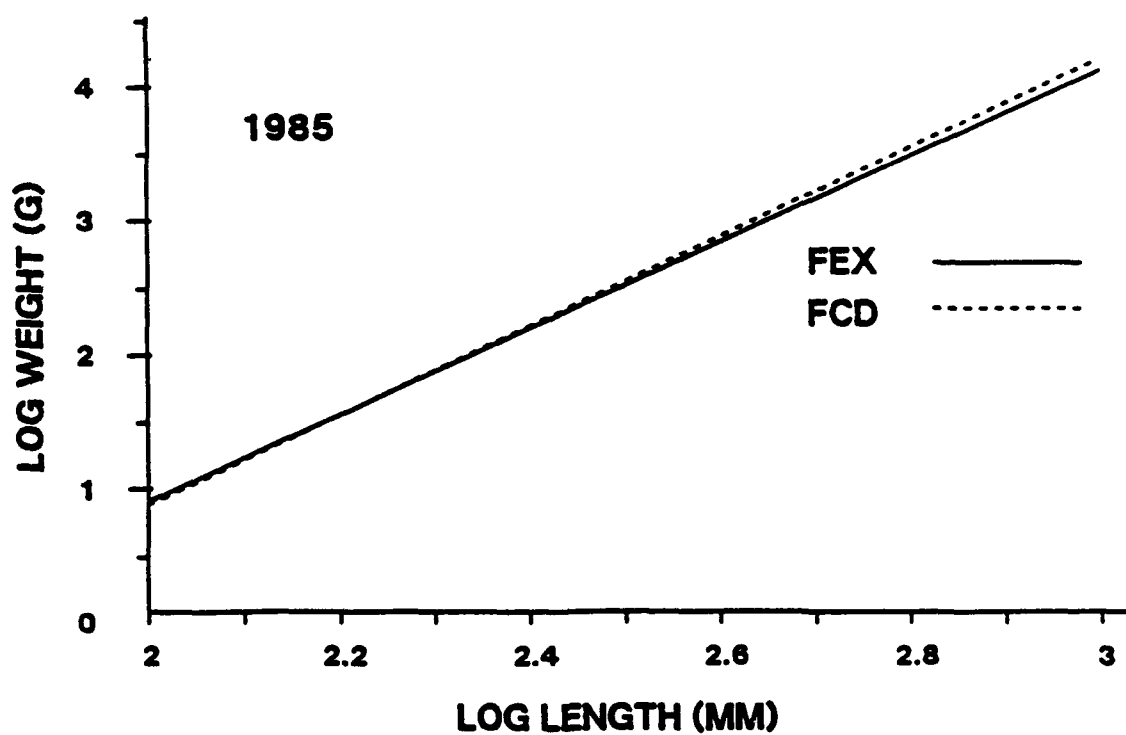
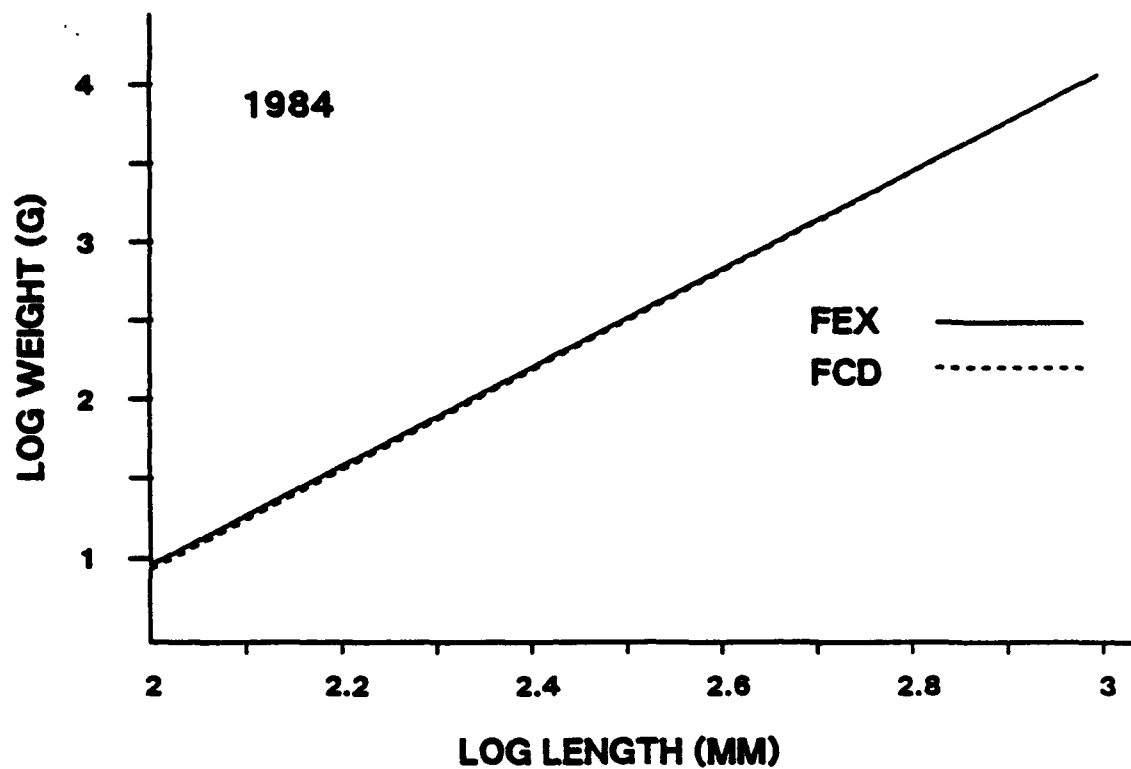


Figure 8.12a. Plot of the regression lines (log wt. vs. log ln.) used in brook trout condition analysis between FCD and FEX in 1984 and 1985.

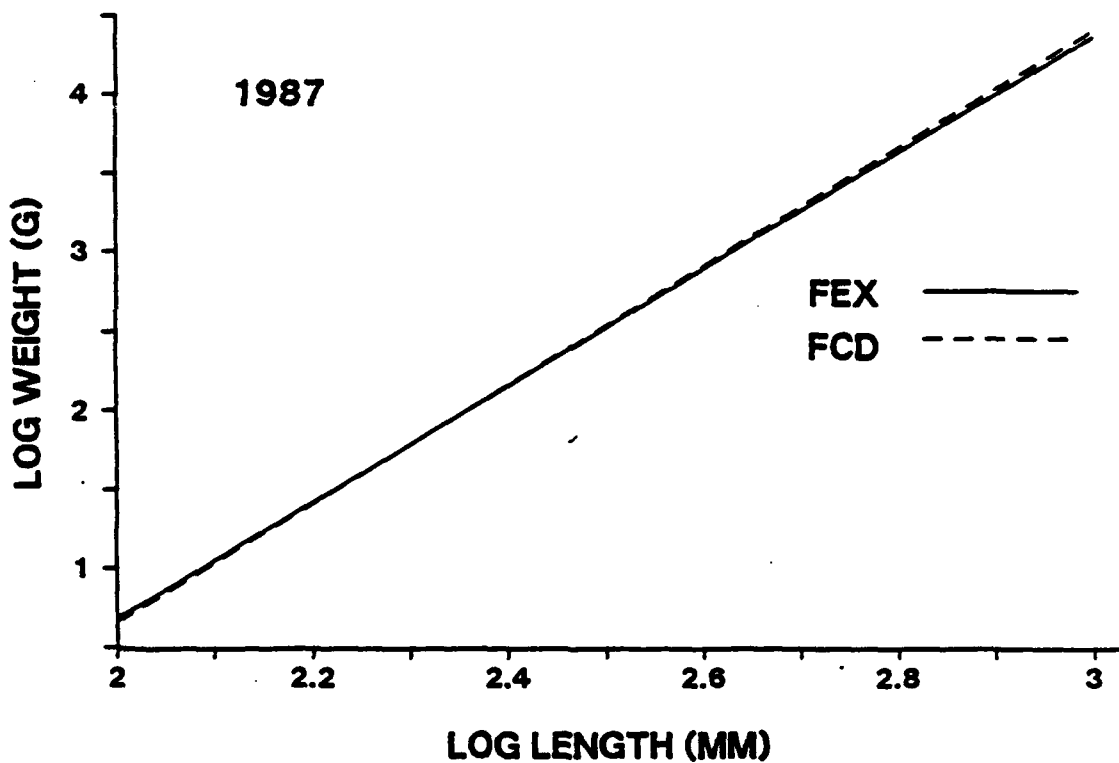
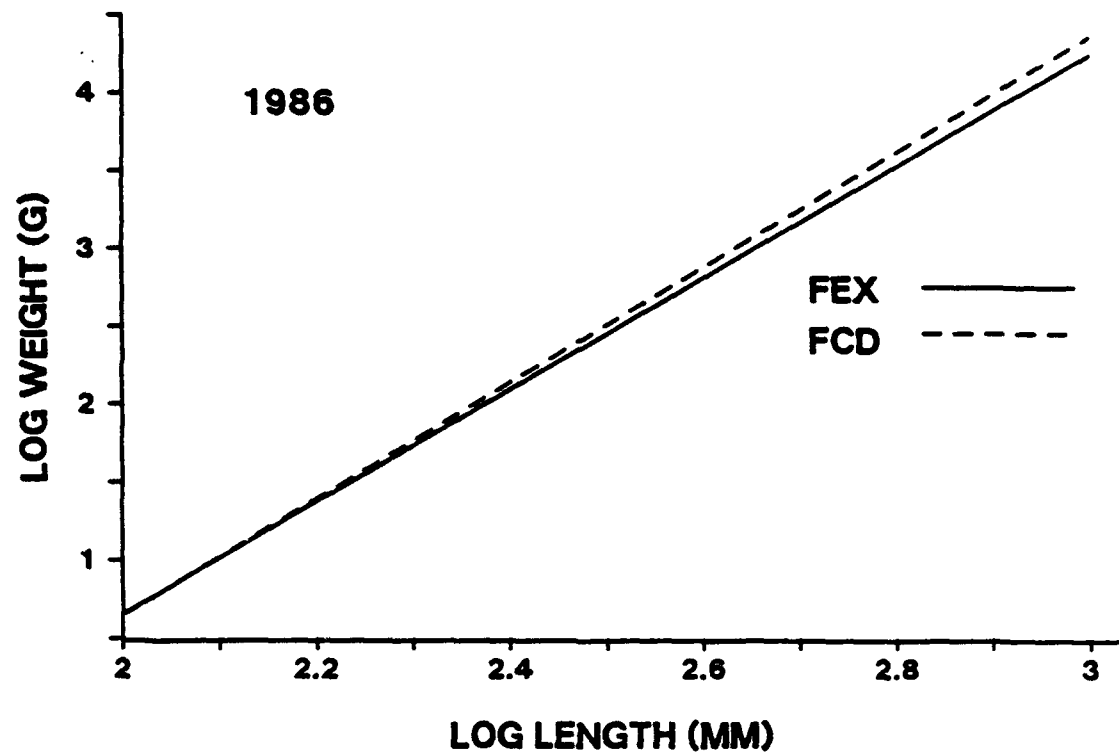


Figure 8.12b. Plot of the regression lines (log weight vs. log length) used in brook trout condition analysis between FCD and FEX in 1986 and 1987.

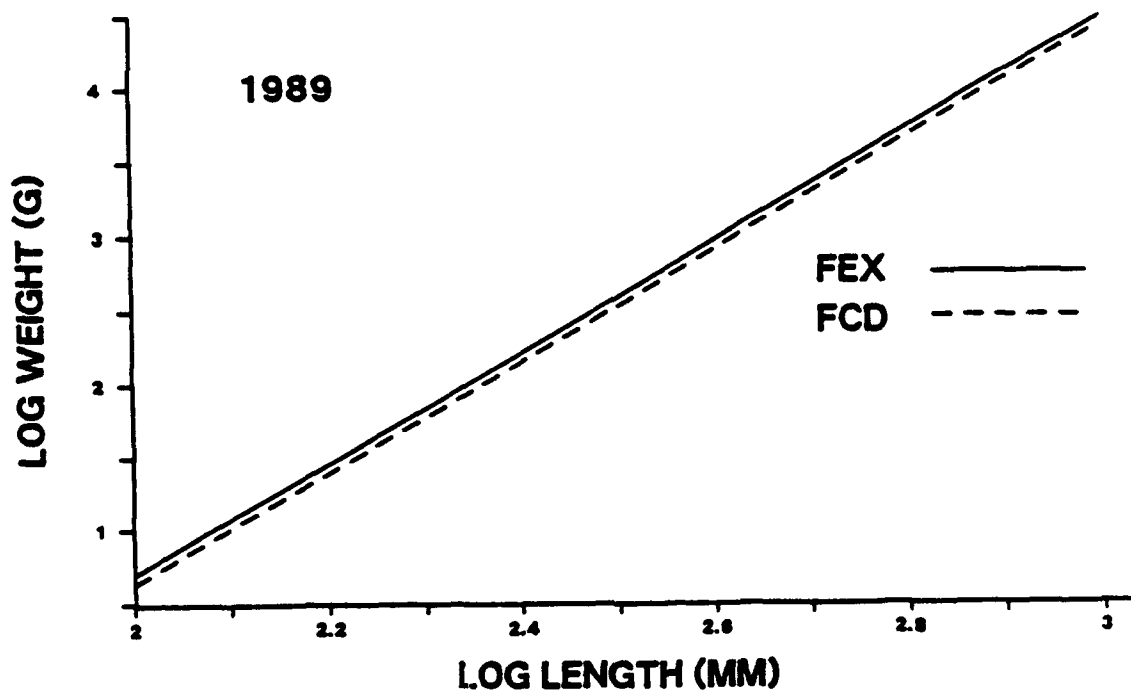
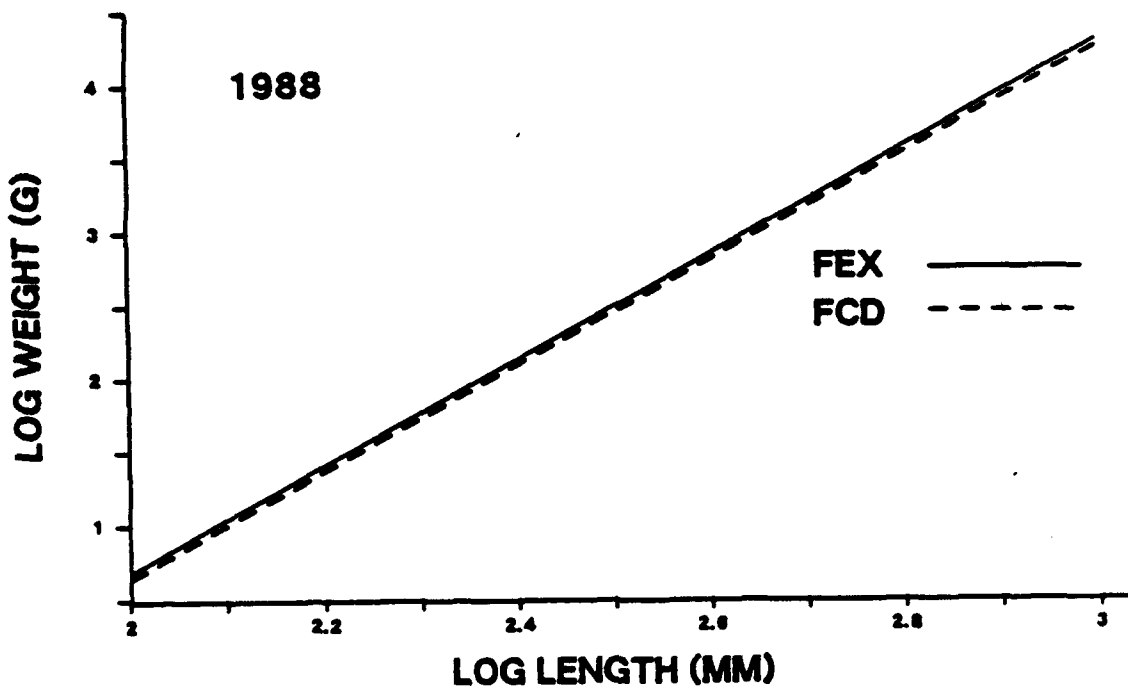


Figure 8.12c. Plot of the regression lines (log weight vs. log length) used in brook trout condition analysis between FCD and FEX in 1988 and 1989.

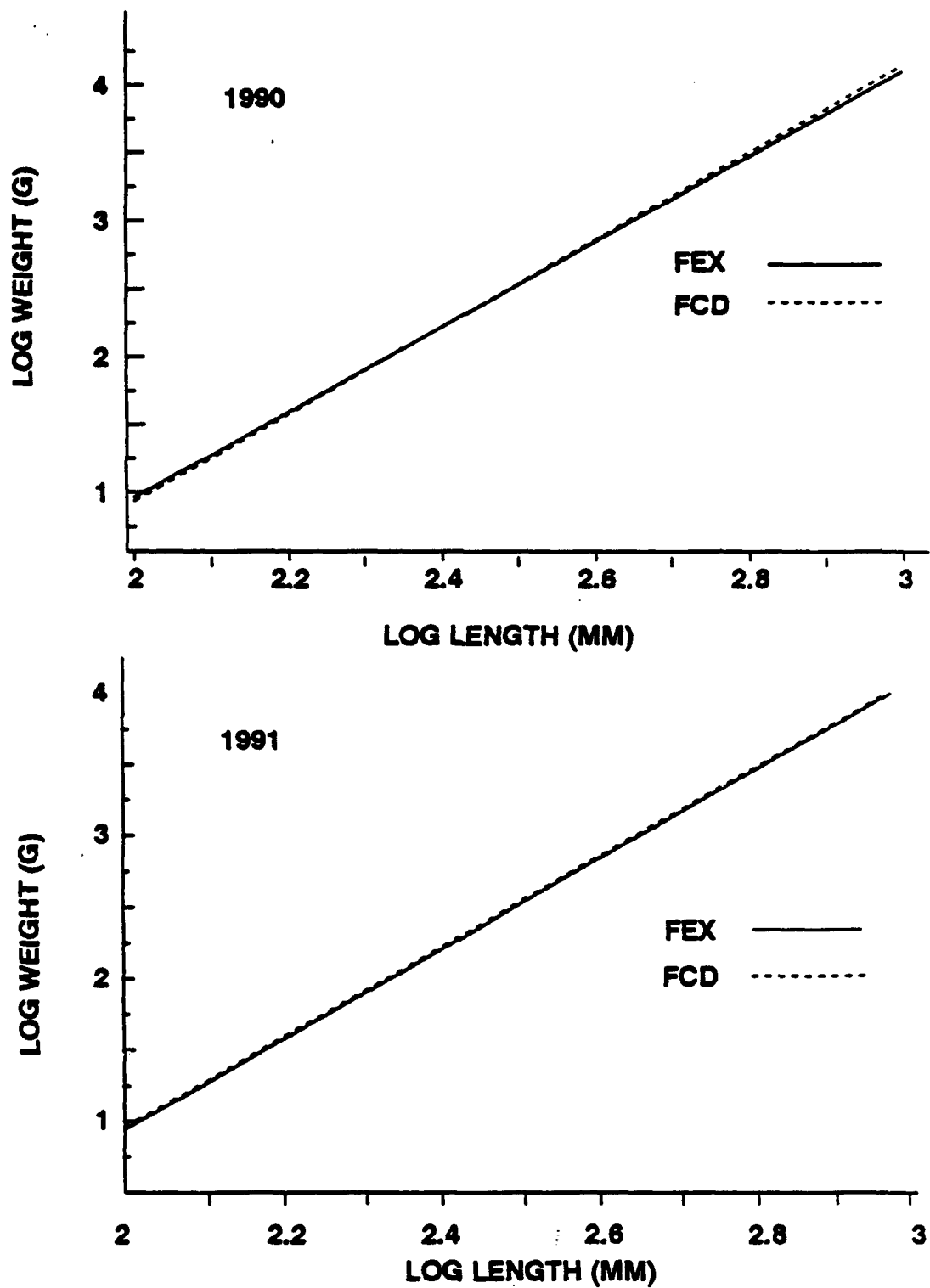


Figure 8.12d. Plot of the regression lines (log wt. vs. log ln.) used in brook trout condition analysis between FCD and FEX in 1990 and 1991.

Covariance analysis was conducted to test for differences in the slopes of the regression lines between pre-operational, transitional, and post-operational years (Figure 8.13). No significant differences were found between the three periods ($F_{5,1695}=0.89$, $p>0.05$) (Table 8.8). However, there were significant differences between the Y-intercepts for the three periods ($F_{5,1700}=3.04$, $p<0.05$) (Table 8.8), but the differences followed no detectable patterns.

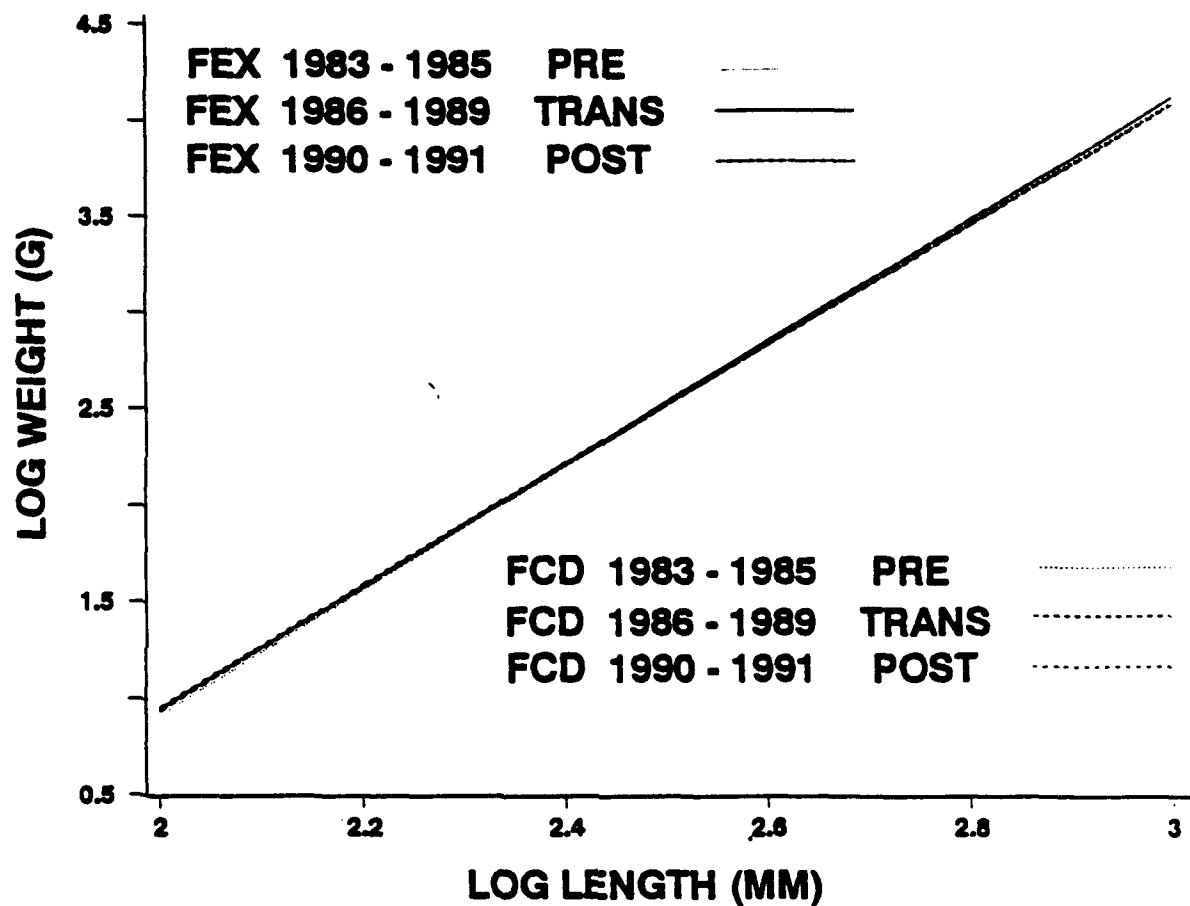


Figure 8.13. Plots of the regression lines used in the covariance analysis of weight vs. length.

Table 8.8. Length/weight regression equations used in the covariance analysis of brook trout condition between periods (pre-, trans-, and post-operational) at FEX and FCD.

		n	INTERCEPT
PRE-OPERATIONAL			
(1983-1985)			
FCD	$y = -5.39 + 3.16x$	385	a
FEX	$y = -5.58 + 3.24x$	218	b
TRANSITIONAL			
(1986-1989)			
FCD	$y = -5.46 + 3.20x$	372	c
FEX	$y = -5.41 + 3.18x$	415	d
POST-OPERATIONAL			
(1990-1991)			
FCD	$y = -5.38 + 3.17x$	153	a
FEX	$y = -5.33 + 3.14x$	164	e

NOTE - Overall test for differences between slopes was non-significant ($F_{(5,1695)} = 0.89$, $p > 0.05$). Overall test for differences between intercepts was significant ($F_{(5,1700)} = 3.04$, $p < 0.05$). Periods within a site having the same letter do not differ at $\alpha = 0.05$ (Tukey - Kramer Multiple Comparison Test, Miller 1986).

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